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GENERAL EXPERIMENTAL PSYCHOLOGY

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GENERAL EXPERIMENTAL PSYCHOLOGY

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First Edition June 1934
Reprinted June 1935, July 1937

PRINTED IN THE UNITED STATES OF AMERICA

PREFACE

THE TITLE of this book, *General* Experimental Psychology, was chosen advisedly. The book aims to encompass a somewhat wider subject matter than has heretofore been included in experimental textbooks. This is necessitated by the rapid expansion of such fields as Learning and Memory, and Work and Fatigue during recent years, which has led to a decided shift of emphasis in experimental courses. On the other hand, no attempt has been made to include all fields of psychology which have yielded large bodies of experimental data, but only those included within the term *general*, i.e., adult, human, normal psychology. The field of Individual Differences has been arbitrarily excluded. Experiments in Animal and Abnormal Psychology have been introduced very sparingly. The emphasis throughout is on fundamental mechanisms.

While the choice of material presented under the various topics is adequate, it is by no means intended to be exhaustive. The most rigid selection had to be made in the case of Sensory Processes, because of the overwhelming mass of data available, and the greater completeness with which this subject has been handled in previous experimental texts. In the case of Learning and Memory and Work and Fatigue a more extensive treatment of recent literature was attempted. References to foreign literature are not extensive, because of the inaccessibility of this material to the average student. It is assumed of course that the instructor will exercise individual judgment in the emphasis he places on particular fields. The makeup of the book reflects not only the author's seven years of experience with experimental classes, but also the

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accumulated lore of those who preceded him in the Chicago Laboratory, particularly Professors Harvey A. Carr and Edward S. Robinson.

No laboratory manual is included in this text, but any number of up-to-date manuals are available. Often the instructor prefers to make his own selection of experiments and techniques to be worked up for the laboratory course. However, the standard techniques used in connection with the various fields have been discussed in the text and illustrations of most of the commoner pieces of apparatus are given for the benefit of students in laboratories whose equipment is limited. Two valuable reference books to be used as supplements to this text are Murchison's *Foundations of Experimental Psychology,* and Boring's *History of Experimental Psychology.*

The bibliography is arranged according to chapters so that a complete list of all works referred to in each chapter appears at the end. By means of these lists the student can supplement the information given in the text with regard to any author's experimental findings. The two appendices are included to assist in the working up of laboratory data, and in case the instructor wishes to make the teaching of a few fundamentals of statistics a part of the experimental course.

I acknowledge my great indebtedness to Professor Harvey A. Carr for having originally suggested the writing of the book, and for having rendered invaluable aid in its preparation. Thanks are due to Mr. Joseph W. Nagge and others for assistance in compiling some of the bibliographies. I also desire to acknowledge my indebtedness to the various publishers who have given permission for the use of cuts and graphs, and to C. H. Stoelting & Co. for furnishing original cuts of apparatus. This acknowledgment extends also to the authors whose tables and illustrations have been used in this volume.

A. G. B.

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GENERAL EXPERIMENTAL PSYCHOLOGY

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INTRODUCTION

THE ASSUMPTIONS, METHODS, AND FIELD OF EXPERIMENTAL PSYCHOLOGY

FUNDAMENTAL ASSUMPTIONS

PSYCHOLOGY, like every science, must begin with certain general assumptions, but at present there is not uniform agreement among psychologists as to what these necessary assumptions should be. The majority, however, agree in classifying psychology among the natural sciences, as a branch of that group of sciences which make living organisms their subject-matter — the biological group. They therefore hold that psychology should be governed by the fundamental assumptions of the natural sciences. Some of these are worth noting.

Explanation vs. Description. — It is the ideal of natural science to deal ultimately in explanatory rather than descriptive concepts. Those who criticize this ideal point out that cause and effect are descriptive concepts, and that scientific laws never achieve more than a descriptive level. Some go even further, and assert that " critical " science, as opposed to " popular " science, should never attempt explanation; that explanation is essentially pseudo-science, striving to go beyond the observed facts, and to deal with hypothetical " Forces " and such animistic survivals of primitive thinking. But this is probably a false interpretation of the meaning of explanation. Truly, explanation is a form of description. But it differs from other forms of description in that it seeks to discover those antecedent factors in the chain of natural events which are *essential* to the appearance of any given phenomenon. In this way it makes possible the prediction and control or manipulation of events. For convenience of formulation the explanatory laws are expressed in terms of hypothetical noumenal concepts, such as matter, energy, et cetera. But these noumenal concepts are recognized to be symbolic, and perhaps ultimately reducible to abstract mathematics. For the present, however, psychology, as a natural and explanatory science, must employ noumenal concepts.

Natural Monism. — Another working hypothesis of the natural sciences is that all observable facts are ultimately explainable on a common basis — the physical continuum. The sciences are built one upon another in a hierarchy, each step up representing a new degree of complexity, from physics and chemistry which deal with the relatively simple material aggregates, to psychology which deals with the most complex. We assume an unbroken continuity throughout. The false conclusion is sometimes drawn from this that the facts of psychology should be stated in terms of the physicist's units — electron, et cetera. But, until the physiologist has reduced his data to these terms, it is hardly to be expected of the psychologist. New levels of complexity necessitate the formulation of new concepts and special laws. To a certain extent phenomena must be dealt with on their own level of complexity. Psychology must content itself with gradually reducing its explanatory concepts to physiological terms; the achievement of this is a sufficiently remote goal. In fact, many data of psychology are doomed to remain on the descriptive level until some radically new basic neuro-physiological hypotheses have been evolved.

Mechanism. — The majority of psychologists are agreed that their science should be completely mechanistic. But there are many meanings of the term mechanism, and it is only in the broadest of these senses that the biological sciences can be said to be completely mechanistic. Certainly it is only by the loosest analogy that a living organism can be spoken of as a machine. About all the term expresses is the working hypothesis that for every psychological phenomenon there can be found adequate antecedents within the natural series of events. This is merely an affirmation of the universality of natural law.

The Operational Viewpoint. — Since an explanatory science must deal in explanatory concepts, we need some criterion of the validity of such concepts. Certainly it is a false notion that a concept gains its validity from the terms in which it is expressed — as though psychological concepts are somehow rendered valid by being expressed in terms of motion, or in terms of neurons, or in terms of algebraic mathematics, or some other preferred medium of discourse. What then is the criterion of a good or valid concept? Bridgman * has pointed out for physics that the validity of a concept is dependent on the validity of the *operations* from which the concept is derived. For, after all, concepts are but symbolic expressions of operations already performed or to be performed. This places a tremendous responsibility on the operations, and with good reason. But it also insures against a very common logical fallacy, that of reification of concepts, and the assigning of indefinite potentiality to them. It also insures against the creation of meaningless concepts. If every explanatory concept is to be the embodiment of real valid operations, there will be fewer sheer flights into the realms of speculative fancy in the process of concept building, and a far greater readiness to abandon concepts which owe their survival merely to their own momentum. An illustration of an operational concept would be Spearman's concept of " G," which is merely a tag for the common factor which has been discovered, by a series of mathematical operations, to be present in a large number of different abilities. The concept is as valid as the operations which gave rise to it, and no more so. Compare with this a concept like " Instinct " which, as usually used, is extremely vague and ill-defined because it is not based upon any valid set of experimental operations.

If, then, the validity of concepts in a science depends so much on the validity of the operations on which they rest, there ought to be certain well defined rules or criteria to guide us in our experimental operations. These will be brought out in an examination of the methods of experimentation.

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* Bridgman, P. W. *The Logic of Modern Physics.* N. Y.; Macmillan, 1927.

THE METHODS OF EXPERIMENTAL PSYCHOLOGY

Historically, psychology has been handicapped, in its struggle to gain scientific status, by the dogma that mental activity must be studied, in part, by a unique method, called introspection in contrast to the natural science method, called objective observation. If this were actually true, psychology would be compelled, either to occupy the unenviable position of a straddler between real and pseudo-science, or to engage in everlasting controversy over the right of its unique method to scientific status. But it is becoming more and more evident, as the smoke of battle clears, that the distinction wrangled over is really one of degree and not of kind. There is only one general method of experimental psychology. It is the method of all science, that of *Controlled Observation,* for the purpose of securing accurate and adequate data on the basis of which to construct a comprehensive explanatory system. But what of the distinction between *objective* and *introspective*?

" Objective " Observation. — The meanings of the term *objective* are too numerous to consider. But as applied to observation it usually means either independent of the observer, or capable of accurate recording and verification by others. Each of these meanings needs elaboration. When is an observation independent of the observer? Obviously, no observation is completely independent, in this sense. No matter how much the astronomer or physicist may desire to eliminate himself from the picture, he must realize that his observations are subject to all sorts of variations due to the fact that he, a human organism, must make and interpret them. But there are degrees of objectivity in this sense. It is the goal of all science, psychology included, to eliminate the observational variable as much as possible. Some classes of data are by nature more infected with it than others. But any scientist who refuses to tackle certain data or to admit the existence of such data merely because they are highly infected with the observational variable, is untrue to his high calling. We want " the whole truth," just as well as " nothing but the truth."

One common method of securing independence of the observer is the use of automatic mechanical recording devices. But not all data can be handled in this manner, and it would be a narrow procedure to exclude everything that cannot be recorded on a kymograph roll or photographed with an electrocardiograph.

Another important method is that of repetition. But if an observation is carefully made, it need not entirely surrender its scientific status because conditions are such that it absolutely cannot be repeated. Some accepted observations of astronomy and geology would have to be rejected if this criterion were insisted upon.

Still another way of eliminating the observational variable is to take advantage of the social check. If several persons observe a phenomenon simultaneously and their reports agree, the personal element is reduced. But in actual practice this ideal is seldom realized and there is substituted for it the ideal that an observation be of such a nature that it *could* be made by several persons simultaneously, if so required, or *could* be repeated as often as necessary. However, this rule is probably subject to exceptions.

There certainly are data, which by nature can only be reported on by one person at a time, that are nevertheless extremely useful to the psychologist even though some would exclude them from the body of scientifically established fact.

"Introspective" Observation.—We have seen that the term objective observation is a relative term, an ideal to be approached rather than an exclusive category. We must now inquire whether so-called introspection is a unique method to be contrasted with it, or whether they differ mainly in degree. There are conflicting definitions of introspection. Some are obsolete, as for example that of an "inner sense," a special sense organ through which one observes his mental behavior. Others are ambiguous, as the statement that introspection is the "direct observation of one's own mental processes." Does this imply that the observer is directly observing some sort of unique content which belongs to a different continuum from the content of objective observation? Or does it merely mean that he is making

sensory reports of what is going on in his physiological organism when he indulges in so-called mental acts such as perceiving, attending, reflecting, et cetera? If the former, then we are dealing with some sort of unique method. If the latter, then it is not the method that is unique. It is merely the fact that attention is being directed to the stimulations of the more obscure sense organs.

There is still another definition of introspection which is that employed by the descriptive or existential school of psychologists. It makes the difference between introspection and objective observation one of point of view only, the data of both being often identical. Thus, if I interpret an observed patch of red as meaning a disc of paper revolving at some distance in front of me, I have made an objective observation. But if I interpret the same observed patch of red as my own sensory content, then I have made an introspection. This distinction was first made by Wundt but has been modified since. Thus, when a naïve introspector takes the " objective-observation " attitude rather than the " introspective " attitude, in the above situation, he is said to be guilty of the " stimulus error." That is, he is guilty of directing his attention upon the stimulus rather than upon his own sensory content as distinct from the stimulus.

Still another definition insists that introspection is essentially retrospection, since no mental act can be observed while it is occurring, for otherwise the observer would have to be at one instant both observer and object of observation. But this distinction is hardly a vital one, since all observation is to a certain extent retrospection.

In most of these meanings of introspection we see that there is no implication of a unique process. In fact, when all irrelevant trappings are removed, it is evident that the only truly unique feature in certain psychological observations is the fact that they are *self observations*. They are made upon the observer's own organism, rather than upon other human organisms. Yet this fact ought not to give rise to the conception of a unique method, for were not Ebbinghaus's * experiments performed on himself? Yet they have not been denied objective status on that account.

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* Ebbinghaus, H. *Memory: a Contribution to Experimental Psychology.* Teachers College Contributions, N. Y. 1913.

Perhaps we should recognize that there is usually a difference in degree of objectivity between self observation and observation of " the other one." The self observer often finds himself struggling heroically to report accurately and quantitatively processes which are so unstable and poorly verbalized that they continually elude him. However, his efforts are none the less valuable because they do not always yield final data, and often serve a mere tentative purpose in directing the efforts of the so-called " objective " observer toward fruitful channels. Sometimes self observers are able to come to better agreement amongst themselves than are " objective " observers; at least they, too, can submit their findings to the social check. Often they are able to repeat their experiments more frequently. One of the chief difficulties in the way of objectification of their technique seems to be in the matter of isolation of the particular process to be observed. Apparatus is occasionally helpful, but in the main the analytical tool is attention, and attention is an extremely unstable tool.

We are now prepared to reaffirm our original contention that there is only one general method of experimental psychology, as of all science, and that is the method of controlled observation.

Psychophysics. — In addition to the exclusive objective and exclusive subjective approaches, there is a method which attempts to determine the quantitative relationship between the two orders by correlating variations in the objective stimulus with variations in the individual's experience. Certain methods of procedure for doing this have been devised, which are known as the psychophysical methods. These methods are described briefly in Appendix B.

GENERAL EXPERIMENTAL METHODOLOGY

The typical experiment involves the selection and isolation of a particular variable for independent study and control. This factor is then held constant and its effects are noted in a series of situations. Or the isolated factor is systematically varied, while the situation is held constant, and the effects are observed. The first problem of experimentation is therefore to be able to properly isolate and control the variable to be studied. Certain methods apply to the control of individual observations. Others achieve control through multiplying the observations and applying statistical analyses to the aggregate data.

Methods of Controlling the Accuracy of Individual Observations

Compared with other sciences, psychology has a peculiarly difficult problem in securing the isolation of variables for study. It is almost impossible to eliminate all irrelevant and interfering factors. The most difficult of all to control is the so-called human factor — the subject's motivation, et cetera. But even the mechanical isolation of the variable to be investigated is always an infinitely more complex task than, for example, the isolation of an element in a chemical compound. In physics and chemistry one often deals with relatively isolated systems. In psychology this never happens except by a process of logical abstraction or the creation of a situation the artificiality of which renders it meaningless for interpreting real life. Yet the sacrifice must be made if any accurate observations are to be obtained.

Mechanical Controls. — These are as various as the problems undertaken. The number of typically psychological precision instruments is gradually increasing; the chronoscope, the tachistoscope, the bradyscope, color mixer, et cetera. Many instrumental techniques have been taken over from other sciences and adapted to our purposes, such as the galvanometer, pneumograph, and spectroscope. A thorough familiarity with the use of all such standard pieces of apparatus is essential to work in experimental psychology. But there is no virtue in apparatus for its own sake. It should not be made an end in itself. Its purpose should never be overlooked, that of securing added control where control is necessary. Beyond this, it merely defeats its own purpose, since it is likely to introduce new sources of error into the situation, and often complicate needlessly an otherwise simple set-up. For example, in studying the free association process, the experimenter might be interested in the time elapsing between the giving of the stimulus word and the subject's response, for diagnostic purposes. Ordinarily this is accomplished with a stop watch, which is subject to a fairly large error of measurement. The time could be most accurately recorded by using a voice key in connection with a Dunlap or Hipp chronoscope. But is there any reason why the experimenter must, in this case, distinguish between the minutest fractions of seconds? Certainly there is no diagnostic significance in time differences under a half second. In such an experiment, then, to use a voice key and chronoscope would be extremely pedantic. And, in addition, it would introduce positive errors due to the very unwieldiness of the set-up.

Controlling the Human Element. — By far the most important controls in the majority of psychological experiments are those which are directed upon the human variable. This applies to the observer as well as to the subject, and particularly to those cases where the observer is the subject. An astronomer can gaze at the planets through his telescope with assurance that the planets will not be driven out of their true courses by his gaze. But the psychological observer can never be sure what influence his mere presence exerts upon the subjects' mental behavior. How serious a matter this is, must be decided in each particular case. An even more serious source of error lies in the variable motivation of human subjects in all situations, but particularly in the artificial laboratory atmosphere. Hull's * study on smoking is a good example of the elaborate devices which must sometimes be resorted to in controlling a subject's motivation.

The Method of Repeated Observations

So difficult is the task of rendering single observations accurate, that experimenters have resorted to the method of repeating them many times. The logic of repeated observations is simply this: provided the disturbing factors which enter into each single observation are not constant, but vary with each one, then if the observation is repeated often enough, these chance variables ought to balance one another in the average, since they are almost sure to have opposite tendencies. Thus the average is in a sense a truer measure than the result of any single observation because chance variables have been cancelled out. Unfortunately, not all disturbing factors can be eliminated in this way, since some are constant throughout the series of measures. The experimenter who can guess ahead of time what these constant factors are likely to be will be in a position to eliminate them. No amount of repetition will avail.

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* Hull, C. L. *The Influence of Tobacco on Mental and Motor Efficiency.* Psychol. Monog., 1924, 33, 1–160.

Statistical Methods of Control. — Growing out of the method of repeated observations there have been devised several statistical methods of dealing with such group data in order to test their degree of reliability and significance in each case. These statistical devices are extremely helpful. An understanding of their use and applicability to particular data is as necessary for the experimenter as is familiarity with apparatus. But they have their limits. They always involve certain assumptions about the way the new data were obtained. Ordinarily, they are useless when applied to a small number of cases. Usually they deal with the chance uncontrolled factors rather than the constant errors; they assume that constant errors have been controlled in other ways. A slavish use of statistics or an unjustified application of formulae is worse than none at all. The most frequently used devices are the measures of variability of averages, measures of reliability of group differences, and the correlation techniques. By the methods of partial and multiple correlation it is sometimes possible to determine the influence of one among several factors when the factor in question has not been experimentally isolated. A brief description of the most essential statistical methods for general experimental psychology can be found in Appendix A.

Statistical and Graphical Methods of Recording Data. — Often the purpose of statistical methods is merely to put raw data into such shape that they can be compiled for preservation and communication to others, or so that laws can be more conveniently formulated from them. Measures of central tendency, measures of dispersion, et cetera, belong to this class. If it is required to express the concomitant variation of two factors relative to one another, the graph is the most convenient device to express the continuous functional relation.

ANALYTIC TECHNIQUES IN PSYCHOLOGY

It has been suggested that psychology has a peculiarly difficult task in isolating and independently varying its analytical units. This is an inevitable outcome of the tremendous complexity of the processes dealt with, and the peculiar barriers in the way of an actual operational separation of one from another for purposes of independent observation. The chemist can apply an electric current to a tube of water and split it into its elementary components, hydrogen and oxygen. A physiologist can remove a bodily organ and note the effect of its loss on the organism, or he can experimentally vary the body chemistry by the addition or subtraction of certain components of the diet. What can the psychologist do in the way of operationally isolating one mental unit or another from the total complex? Practically he has devised several different techniques for this purpose, some of which have already been worked out, and have yielded fruitful results. Others have been tried and abandoned as unproductive; still others have yet to be exploited. Some of the typical techniques will be mentioned.

Isolation of Structural Parts of the Organism. — This method is the most direct and obvious one, since mental activities take place in a physiological milieu. It is borrowed from physiology but has been applied in quite original ways by recent psychologists. Extirpation of parts of the central nervous system in animals and a study of the effect of such loss upon the animals' behavior patterns has been used effectively by Lashley. It is obviously limited to animals, though the implications for human subjects are clear enough. In those cases where nature has set the experimental stage itself, i.e., where disease or injury has resulted in the loss of cerebral structures in human beings, with correlated loss of functions, an entering wedge is given; but nature's technique is likely to be poor, and the implications from such conditions are not clear.

The artificial or natural severing of peripheral nerve trunk, or sensory end organs, with attendant functional disturbances, has made the exact knowledge of peripheral sensory and motor innervation possible. But such methods are not limited to the nervous system. Conditions of gland disfunctioning, systematic variation of diet and digestive processes, artificial increase or decrease of particular hormones, all throw light on mental characteristics.

The method of mechanical interference with the functioning of particular bodily structures and the artificial alteration of the body chemistry are still in the exploratory stages. Drugs have been used effectively in the field of sensory processes where selective anaesthesia has demonstrated the structural and functional independence of particular sensory qualia. But the use of drugs in studying the higher mental processes selectively is still unexploited. Sometimes the method of mechanical isolation amounts to nothing more elaborate than blindfolding the subject or plugging an ear. The less we know about the exact way in which we have altered the condition of the organism, the less profitable is the procedure. This is true, for example, of the hypnotic technique until more is understood about the nature of the dissociations produced by it.

A method related to the foregoing is that of construction of physical models whose analogy to the probable workings of the human mental mechanism makes them suggestive bases for hypothesis building.

Control of the Stimulus-Response Situation.—It is possible, without mechanically interfering with the parts of the organism in any way, to study the independent operation of mental functions by systematically altering the stimulus-response situation in various ways. The concepts which are constructed on the basis of such manipulation are not easily transformable into neuro-physiological concepts or organismic concepts such as result from the previously described technique. They are based on logical or functional distinctions rather than on spatio-temporal ones. Their neuro-physiological significance is bound to be obscure. This, however, is no condemnation. Their behavior significance is fully as great, and, in practical life, much greater than that of strictly neural concepts. And the implication is that they do have their neurophysiological synonyms, which will one day be defined.

An example of this technique of manipulating the stimulus situation is seen in the method of isolating binocular parallax as an independent cue in perception of depth, by means of the stereoscope. Another example is the systematic elimination of sensory cues in animal maze learning. Practically every experiment involves isolation and manipulation of the stimulus situation in one way or another.

The controls exerted on the response situation are fully as important. Stomach balloons, moving picture cameras, plethysmographs, galvanometers, all are directed toward the isolation and independent registration of particular aspects of the response pattern.

Analysis of Product. — This method belongs logically in the preceding category, but since it often depends for its effectiveness on mass treatment of product, rather than on isolated study of response patterns as such, it deserves separate mention.

Psychological tests of all sorts belong in this category in so far as their function is really experimental. It is well to distinguish between the use of a test as a test, and as an experiment. Testing as testing is designed to find out some fact about an individual in order to evaluate that individual for practical purposes. Whereas in the experimental use of testing, the purpose is to find out some fact of strictly theoretical interest about individuals in general or about a certain class of individuals, by testing a large number of subjects from which averages can be secured. Thus, to use the Binet test to find out the I.Q. of a certain particular child is to use it for testing purposes. But to use the Binet tests to find out the growth curve of intelligence is to perform a psychological experiment.

Where product is the feature analyzed the units of analysis are usually evaluative, rather than explanatory. The human thinking mechanism is treated as an engine, and the product is evaluated in terms of its conformity to certain ideal standards, such as speed, quality, or energy consumption per unit. The purpose is to gain a measure of the subject's "Power." Woodworth has compared this procedure to the measurement of power in physics, where power represents rate at which work is done and is expressed by the formula M a S / t, where M equals mass moved; a equals resistance; S equals the distance moved, and t equals the time necessary to do it. The analogous psychological formula becomes Power equals *Quantity* times *Difficulty* times *Excellence* divided by *Time.* The psychological problem becomes one of holding three of these factors constant and varying the fourth. The factor to be varied decides the method used, whether it shall be a time measuring method, a quantity measuring method, an excellence measuring method, or a difficulty measuring method. Such concepts as fatigue, decrement, intelligence, abnormality, efficiency, et cetera, have as yet only the vaguest significance in terms of process. These concepts must be replaced ultimately by those of an explanatory order; but, like the descriptive concepts of existential psychology, they do throw light indirectly on the fundamental mental mechanisms and they give the experimenter fruitful leads.

A unique and promising method of analysis through testing is the Spearman* group factor method. This method attempts, by a statistical analysis of test performances, to factor out certain fundamental general elements which contribute to excellence of performance in a large number of operations. It seems an easy step from such analysis to the discovery of the mental mechanism involved but experience shows that the step is not so easily taken. If there is a neural "G," is it energy, or volume of cortex, or what?

A step in advance of Spearman's technique is Thurstone's Multiple Factor Analysis technique.

Controlling the Genetic Development. — An extremely promising technique in experimental analysis of mental mechanisms is that of controlling their ontogenetic and phylogenetic development. The psychological methods are better designed to deal with ontogenetic development, but a study of heredity must go hand in hand with a study of the effects of nurture. What are the intellectual resemblances of identical twins as compared with siblings? To what extent are these native resemblances and differences altered by environmental factors, training, and disease? What emotional patterns are native? A study of the genesis of habits in childhood as well as in adulthood, throws light on the analytical components of complex mental integrations. The study of animals has a genetic significance in throwing light on the primitive forms of human mental mechanisms. And many techniques can be used on the animal which would be practically or wholly prohibitive in the case of human subjects.

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* Spearman, C. S. *The Abilities of Man: their Nature and Measurement.* N. Y. Macmillan. 1927.

Even the anthropological technique, which attempts to get at the genetic stages in the development of human cultural institutions, has a legitimate place in broader interpretations of the field of experimental psychology.

Self-Observational Analysis. — Last but not least, the so-called introspective method of studying mental processes or mechanisms directly in oneself, while they are taking place, is a technique which is bound to be fruitful in developing leads and suggestions even though the peculiar obstacles to objectifying the procedure are likely to give its data a lack of scientific finality. The concepts developed through an attentional analysis of mental acts while they are taking place are not immediately identifiable with the concepts developed in other ways but the lack of agreement is probably not an ultimate one. No doubt any one of these concepts will be interchangeable with those of any other of the methods eventually. By the very necessity for interchange, they will approach a common middle ground of meaning. Just as mental content concepts will become more organismic so will neuro-physiological concepts become less anatomical and more dynamic. The results of Lashley's * research point very definitely in this direction already. The ultimate concepts will be more broadly representative of the universality of the underlying operations involved and less narrowly representative of the particular technique used.

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* Lashley, K. S. *Brain Mechanisms and Intelligence.* Chicago Univ. Press, 1929.

Mind-body dualism has been kept alive by the necessity of attacking mental mechanisms from different angles. There has existed, not a " double aspect," but a multiple aspect point of view. But the psychologist is blind who cannot foresee the ultimate meeting of these multiple concepts in a common set of operational concepts for psychology.

THE FIELD OF EXPERIMENTAL PSYCHOLOGY

From what has been said in the previous paragraphs it is apparent to the reader, that there is no rigid or restricted field of experimental psychology. Whatever experimental technique, or whatever angle of experimental attack throws light on the nature of mental mechanisms is a legitimate one for experimental psychology. It is the use of the method of controlled observation, rather than the particular field or viewpoint, which characterizes experimental psychology. The only restriction is that the findings must have a general significance for human behavior. However, there is a body of data collected with respect to normal adult human psychology and this constitutes the traditional field of experimental psychology. This book will therefore be restricted to that field, which might be designated the field of General Experimental Psychology.

Even with the above restriction of the field it is not self-evident what material should be admitted and what excluded. There is plenty of historical precedent for including simple sensory processes though much of the material is borrowed from physiology and many of the problems are more physiological than psychological. On the other hand, there is an equal logical justification for including motor processes; yet historically the subject matter has been largely excluded. Actually the problems are best conceived as sensory-motor and permit of division into the sensory and motor aspects merely for convenience in splitting up the subject matter.

The subject of affective and emotive processes has not been systematically studied until recent years so that it constitutes a new but extremely important body of material. Some good experiments have been recorded though they lack the authoritative finality of the longer established material.

Probably the most important single subject of general psychology is learning. This, again, is a relatively recently developed field and the current experimental texts either omit it or relegate it to a very subordinate position. This position is entirely incommensurate with the body of data and with the attitude of contemporary psychologists which is that learning, more than any other subject, constitutes the typical psychological problem. This topic, therefore, has been stressed in the following pages.

The so-called higher thought processes still occupy a minor position in the experimental scheme, and justly so. Their complexity practically necessitates the postponement of analysis until the simpler component mechanisms are better understood. Imagery and meaning are disputed ground, which has been temporarily abandoned as no man's land, although it is not at all certain that the subject matter deserves this fate or that it has no important implications for an understanding of fundamental mental mechanisms. Recently some careful experiments have been performed on concept formation and on reasoning.

The study of the organism at work and of the conditions of mental efficiency now contribute an important body of knowledge to experimental psychology. A section of the book has therefore been devoted to the topic of " Work and Fatigue." The present volume is divided as follows: Part I, Sensory Processes; Part II, Perception; Part III, Learning and Memory; Part IV, Association and Thought; Part V, Work and Fatigue; Part VI, Affective and Emotional Processes.

Part One—Sensory Processes

CHAPTER I

THE NATURE OF SENSORY PROCESS

THEORETICALLY there is no justification for separating sensory processes from the total response pattern of organisms. The separation is a logical one for convenience of study. Actually one does not find sensory reactions distinct from central or integrative reactions, and these again distinct from motor reactions. Rather, one finds sensory-neuro-muscular response patterns. It has been pointed out that the co-operation of the whole organism is probably necessary for the act of sensing or becoming aware of the environment. The whole sensory-neuro-muscular and glandular system constitutes the Sensorium, or complete mechanism of sensing. This is equally true whether one examines the organismic process physiologically, or analyzes the content of sensory experience. Sensory experience does not present itself as a mere point for point projection of stimulus patterns. First, the action of the sense organ itself modifies the original pattern; then it is further modified by the afferent nervous system, and by the central integrative brain process. And finally, during the process, anticipatory motor and glandular reactions have already begun to take place and these alter the pattern of the sensory experience. For example, in the act of visually sensing or becoming aware of a snake, the mere pattern of visual stimulation is a minor factor in the experience pattern. The chills along the spine, the withdrawing attitude, dictate the experience pattern quite as much. In fact, if we go back in the evolutionary scale and examine the very earliest counterpart of "sensing," in unicellular organisms like the amoeba, we find it in the function of irritability. But irritability is merely a logical aspect of a unitary process, which involves also conductivity and contractility. And all three of these phases constitute one process, which is the function of the protoplasmic mass as a whole. Now in higher animals each of these three functions has its specialized structure. The sense organs are specialized structures for irritability, the nervous system is a specialized structure for conductivity and integration, and the muscles and glands are the specialized effector organs. But functionally the separation is a logical one only.

A study of sensory processes is made from three angles, the physical, the physiological, and the experiential. The physical approach involves an analysis of sensory stimuli. The physiological approach consists of an analysis and description of the structure and operation of the sense organs and accompanying neural mechanisms. The experiential approach involves an analysis of the phenomena of sensory experience. Practically, however, these angles of approach are not distinct. All three are studied in terms of their bearing on one another. Only those characteristics of stimuli are examined which enable one to understand how they differentially stimulate sense organs. The physiology of sense organs and nerves helps in an explanation of how the pattern of sensory experience is formed, and the pattern of sensory experience throws light on the physiological process.

Sensory Process in General. — From the primitive condition in which protoplasm responded in an undifferentiated way to stimuli a gradual process of specialization has taken place. The receptor mechanisms have developed as specialized structures for receiving stimulations and each particular receptor mechanism has developed in such a way as to most effectively receive a particular kind of stimulus. This specialization involves the development of two sorts of structures: those for the more adequate reception of the particular stimuli; and those for the exclusion of all other stimuli. Thus the retina of the eye is sensitized to light waves but relatively isolated to contact, et cetera. It is therefore possible to classify the stimuli to a given sense organ as adequate or inadequate, depending on whether that sense organ is specially adapted for their reception or not.

Stimuli may be classified in two ways: in terms of the sense organ to which they are adequate; or in terms of the form of physical energy involved. Organisms are only sensitive to a limited number of the forms of physical energy surrounding them. These are either mechanical or chemical and of the mechanical stimuli the vibratory are the most important. Three large classes of vibratory stimuli can be distinguished: namely, the rhythmically repeated mechanical impacts which give rise to the sense of touch; the vibrations of the surrounding material medium giving rise to sound; and the much more rapid vibrations in the so-called immaterial ether of space — the waves of radiant energy. Not all of these immaterial vibrations are capable of stimulating the sense organs. Only a limited range is responded to. No human sense organ can respond directly to the long electric waves nor to the short ultra violet rays and X-rays. The eye is sensitive to a limited range of ether waves, from 400 to 800 millionths of a millimeter, or millimicrons. These are the light waves. The skin is sensitive to ether waves from 400 millimicrons up to a tenth of a millimeter in length. These are the heat waves which excite the temperature sense.

There is a disagreement among physicists as to the exact nature of transmission of radiant energy. It presents certain characteristics which are best expressed in the concept of undulations in an all pervasive medium and others which call for a concept of energy particles projected through space in a wave-like manner. But the distinction is unimportant for the psychologist since, in either case, the essential feature is the propagation of energy through space, the dimensions of which can be correlated with qualitative and quantitative aspects of experience.

Nature and Classification of Receptor Mechanisms. — According to Sherrington, " The main function of the receptor is, therefore, to lower the threshold of excitability of the arc for one kind of stimulus and to heighten it for all others ": *

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* Sherrington, C. S. *The Integrative Action of the Nervous System.* New Haven: Yale Univ. Press, 1906, p. 12.

Hence each receptor can be shown to consist of a collection of highly sensitized cells capable of reacting to particular kinds of physical energy, and the accessory structures required to facilitate the adequate reception of such forms of energy and to shut out other forms.

Sense organs have been variously classified. The following arrangement takes advantage of several of these classifications:

I. EXTEROCEPTORS
   1. Visual. (Retina) Sensitive to ether vibrations between 400 and 800 millimicrons in length.
   2. Auditory. (Ear) Sensitive to vibrations of surrounding media, chiefly air, with frequencies between 15 and 40,000 vibrations.
   3. Cutaneous. (Skin) Contact—sensitive to mechanical pressure.
      Warmth—sensitive to temperatures above 32 Centigrade.
      Cold—sensitive to temperatures below 32 Centigrade.
      Pain—Sensitive to wide variety of stimuli.
   4. Olfactory (Nasal membrane) Sensitive to chemicals dissolved on olfactory membrane of nose.
   5. Gustatory (Tongue and fauces) Sensitive to chemicals dissolved in mouth.

II. PROPRIOCEPTORS
   1. Kinaesthetic (Muscle spindles, tendon terminations) Sensitive to movements of muscles, tendons, and joints.
   2. Static (Semicircular canals and otolith organs) Sensitive to movements of head and body.

III. INTEROCEPTORS
   1. Hunger (stomach walls)
   2. Thirst (throat membrane)
   3. General intraorganic sensitivity (viscera)

Of these, the exteroceptors have been given the most attention by psychologists since they offer the most clean-cut experimental approach. Experimentation has been most extensive upon vision, audition, and cutaneous sensitivity. Olfaction and gustation offer peculiar difficulties of experimental control which render the results in those fields doubtful.

Experiential Analysis. Qualitative and Quantitative Dif-

ferences in Sensation.—The stimulation of each receptor gives rise to a type of sensory experience which is distinctive, and which differs qualitatively from that of any other receptor. These distinct types of experiences are designated the sense modalities. The unit of sense experience is designated the sensory element, or sensation. Sensations differ both qualitatively and quantitatively.

On the quantitative side, sensations differ in intensity. These differences are correlated—though not perfectly—with differences in the strength of the stimulus. The study of the relation between stimulus intensity and the resulting sensation intensity is known as psychophysics and has given rise to the psychophysical methods. For each sense organ there is a lower limit of intensity which the stimulus must reach in order to produce an appreciable sensation. This is the absolute threshold. There is also an upper limit of intensity of the stimulus and any increase beyond this amount will fail to add to the intensity of the sensation. This constitutes the upper threshold of sensitivity. Between these two extremes the sensation intensity varies with the stimulus intensity but not proportionally. If the increase in the stimulus intensity is very slight it may produce no appreciable change in the sensation intensity. The least amount of increment in the stimulus intensity which can just be noticed is known as the "just noticeable difference," or J. N. D.

The difference in stimulus intensity necessary to produce this differs not only for different sense modalities, but within a given sense modality it varies throughout the range of intensities between the upper and lower thresholds. The size of the increment of stimulus intensity necessary to produce a J. N. D. is called the difference threshold. This increment varies with the absolute intensity of the stimulus. In the median range it is found to be directly proportional to stimulus intensity. Whatever the value of a stimulus (S), in order to produce a just noticeable increase in the intensity of the sensation (R), it will be necessary to increase S by KS, where K represents a constant fraction. This is expressed in the formula $S = K \operatorname{Log} R$, called the Weber-Fechner Law. The relation was originally supposed to be universal but has since been shown to apply only within the median range of intensities and for certain modalities. The quantitative procedures for studying intensity thresholds and difference thresholds are known as the psychophysical methods. For a statement of these methods, refer to the Appendix.

On the qualitative side, sensations differ, first in the modality to which they belong, as visual, auditory, et cetera; and secondly, they vary widely within any given modality. Visual sensations differ in hue and saturation, auditory sensations in pitch and timbre, et cetera, so that there have been distinguished some 30,000 different spectral qualia and some 11,000 different tones or auditory qualia. These qualitative differences within a single sense modality are assumed to give evidence of differences in the nature of the physiological processes involved. These differences may be due to structural differentiations within the given sense organ, or to differences in the neural tract or center involved. One of the aims of psychological experiments is to discover the structural differences which give rise to these qualitative distinctions in experience. The logic of the theories of color vision, for example, consists in fitting a consistent physiological theory to the known facts regarding the behavior of the visual qualia when they are systematically varied in every possible way. The qualitative series are not entirely independent of intensity variations, particularly at the upper and lower thresholds. Thus a very intense red will pass over into white and a very low intensity of red becomes dark gray. But in the main quality and intensity constitute distinct attributes or dimensions of sensation.

Two other dimensions of sensory elements having relatively slight significance compared to the preceding are extensity, which is only characteristic of certain sense modalities, and duration or protensive magnitude, which is a common dimension of all.

Specific Nerve Energy. — The doctrine of specific energy of nerves was first formulated by Johannes Müller in 1826, although the observations which gave rise to it were reported earlier by Charles Bell. The doctrine states that each sense organ, when stimulated, reacts with one definite quality or energy, regardless of the specificity of the stimulus acting upon it. The experimental evidence cited in defense of this theory is: — first, when sense organs are stimulated by inadequate stimuli they nevertheless react in a characteristic way. Cutting the optic nerve gives light sensations; mechanical stimulation of a cold spot on the skin gives a sensation of cold; electrical stimulation of the tongue gives taste. Müller assumed that this specific energy or quality was inherent in the nerve connecting the sense organ with the brain, since stimulation of the nerve between sense organ and brain also produces the specific quality of sensation characteristic of that sense organ. For example, cutting the optic nerve produces a flash of light. In recent times the tendency has been to attribute the specific energy factor to the center in the brain in which the afferent nerve from that sense organ terminates. There is evidence that impulses in different nerves are not qualitatively different, and, within limits, any nerve, by proper crossing, can be made to transmit impulses from different sense organs or to different muscles interchangeably. Langley showed that impulses which normally produce cardiac inhibition can be made to produce contraction of arterioles, and vice versa. Some evidence exists that impulses from certain different cutaneous end organs travel over the same fiber. William James expressed the condition figuratively when he said that if the peripheral end of the auditory nerve were attached to the retina, a person would hear lightning; and if the peripheral end of the optic nerve were attached to the cochlea, he would see thunder. The doctrine stated in this form puts the burden of the qualitative specificity on the cortical projection center and assumes that there is a structural difference corresponding to every qualitative difference within a sense modality, as well as to those between modalities.

Adrian has demonstrated that the frequency of action currents in peripheral nerves varies with the strength of the stimulus and it has been suggested that some subjective differences in sensation quality are produced in this way. For example, the difference between a sensation of contact and a pain sensation. Due to the inadequacy of the evidence, this is all highly speculative. Some differences in sensation are obviously due to structural distinctions in the sense organ. Perhaps others are attributable to the afferent nerve, and certainly all must ultimately depend on specificity in the brain process.

REFERENCES

Adrian, E. D., & Zotterman, Y. The impulses produced by sensory nerve endings. Part 2. *J. Physiol.,* 1926, 61, 151–171.

Carmichael, L. An evaluation of current sensationism. *Psychol. Rev.* 1925, 32, 192–215.

Fechner, G. T. *Elemente de Psycophysik.* Leipzig: Breit Kopf and Hartel, 1889.

Langley, J. N. " On the union of cranial autonomic (visceral) fibres with the nerve cells of the superior cervical ganglion." *J. Physiol.,* 1898, 23, 240.

Müller, Johannes. *Elements of physiology.* Transl. by Baly. London, 1848, pp. 1059 ff.

CHAPTER II

VISUAL PROCESS

NATURE OF THE ADEQUATE STIMULUS

THE adequate stimulus to vision is the light wave. Light is regarded objectively by physicists as consisting of radiant energy emanating from luminous bodies and propagated through space in an undulatory (wave-like) manner. One theory conceives the waves to be oscillations of the particles of an hypothetical medium (ether) which pervades all space. These particles along a ray of light are supposed to have a pendular oscillation in paths at right angles to the ray. This gives the effect of waves in the medium like the smooth ripples on the surface of a lake. An opposing theory conceives of minute energy particles traveling through space from the luminous body along the lines of the rays. This theory also fits in with the undulatory concept, since the energy particles, or photons, are supposed to travel in wavelike paths. Hence the undulatory propagation is the essential feature of both theories and it is immaterial which theory is accepted. It is necessary to study the characteristics of the light ray, in order to understand the physical basis of vision.

The Light Wave may be said to have two dimensions, amplitude and length. In the figure, amplitude is represented by the vertical distance from crest to base. It determines the intensity of the light. Length is represented by the distance from trough to trough horizontally. Since all light waves travel at practically a uniform rate of 186,000 miles per second, the length of a wave has a perfect inverse ratio to its frequency. The shorter the wave, the more frequent are the pulsations. Differences in wave length give rise to differences in the quality of the light sensations. But whereas there is a continuous series of fine gradations in wave length throughout the visible series of wave lengths from the shortest, which is 400 mμ (millionths of a millimeter) to the longest, which is 800 mμ, there is no such continuous series of equal qualitative gradations in sensory experience. Instead, there exist, in the visual spectrum, a limited number of long stretches of relatively uniform quality, with relatively abrupt transitions between. These uniform stretches constitute the fundamental hues, in color vision. It is possible to define any spectral hue by naming its wave length. It happens that there are certain dark lines in the solar spectrum, absorption lines, called the Frauenhofer lines, arranged at intervals. These lines divide the spectrum into regions which correspond roughly to the limits of the different major hues. The following chart gives these relationships:

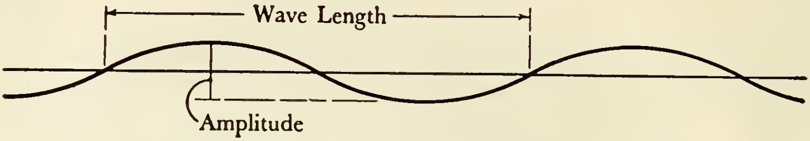

FIG. 1. Light wave

Frauenhofer Lines	*Wave Length (millimicrons)*	*Color*
A	760	Extreme Red
B	686	Red
C	656	Limit of Red & Orange
D	589	Golden Yellow
E	526	Green
F	486	Cyanean Blue
G	430	Limit of Indigo
H	396	Limit of Violet

It is evident that the wave length of the light ray is only one of the determinants of color experience and that the division into a few simple hues is a function of the physiological processes involved.

The Light Ray. — Light rays, as they come directly from the sun or some other luminous body, are complex, consisting of a mixture of all the wave lengths. Such rays are seen as white light. But it is possible, by the use of selective filters, to allow waves of only one length to reach the eye, at one time, and such light is monochromatic, or very close to it. It is possible, by introducing a prism into the line of the complex ray, to split it up by dispersion, i.e., the differential refraction of the different wave lengths, into its component waves. Under these conditions, all the distinguishable hues are seen spread out in the form of a band known as the prismatic spectrum. The best instrument for demonstrating this is the spectroscope. Another method is that of diffraction, by passing the white light through an iron grating. The latter method distributes the bands of color proportionately to the distance apart of their wave lengths.

Light rays may be affected by intervening media in four different ways, depending upon the composition of the medium. They may be transmitted, refracted, absorbed, or reflected. If the medium is translucent, and the ray strikes its surface perpendicularly, it will be *transmitted* directly; if at an angle, it will be *refracted,* i.e., bent. Some media transmit only one of the wave lengths, or a limited number, and *absorb* the others. (Such media are used as filters. Red glass transmits red rays, and absorbs most of the others; but a spectroscopic analysis shows that it is not a perfect filter. Gelatin filters, such as the Wratten lenses, can be made to transmit monochromatic light or any combination of lights desired.) Opaque media either *absorb* or *reflect* light. Most objects have a characteristic color, because the pigments on their surfaces reflect that particular wave length and absorb all the other wave lengths.

INADEQUATE STIMULI

In addition to being stimulated by light rays, the retina responds to various inadequate stimuli. Pressure on the eyeball causes a phosphorescent arc to appear in the visual field opposite the point stimulated. Electrical currents give rise to sensations of black, green, and yellow at the positive pole, and white, red, and blue at the negative pole. A blow on the head gives complex visual experiences, as does cutting the optic nerve. The theoretical significance of this will be seen later.

GROSS ANATOMY AND PHYSIOLOGY OF THE EYE

FIGURE 2 gives a cross section of the eye. It may be compared to a photographic camera in which the eyeball with its three layers, sclerotic, choroid, and retinal, forms the dark chamber 24 mm. in depth and the retina is the sensitive plate at the rear. The lens system for focusing the image on the retina consists of four parts. The first lens is the cornea, a transparent bulging portion of the sclerotic layer, directly in front. The second lens is the aqueous humor, a transparent liquid which fills the aperture between cornea and iris. The iris,

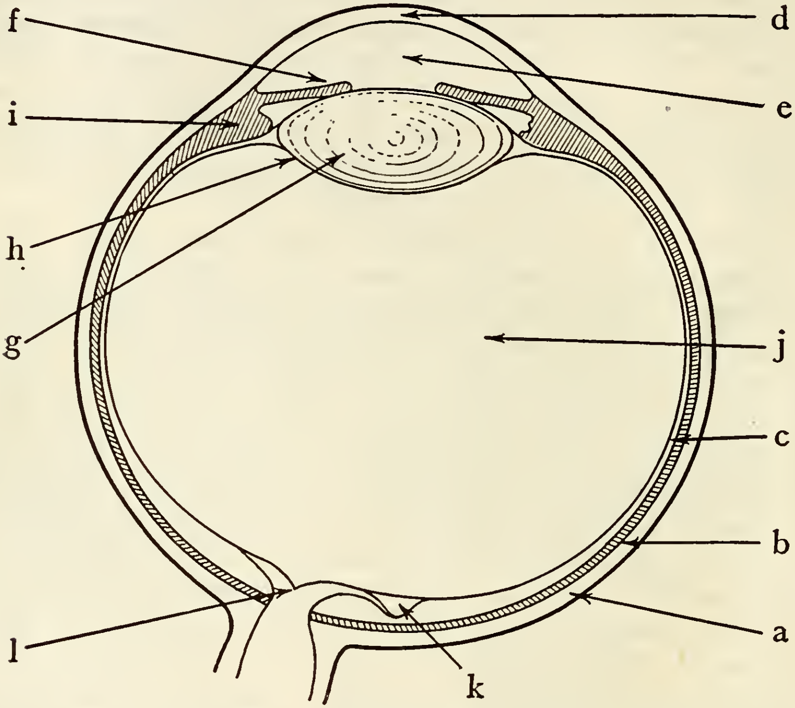

FIG. 2. Cross-section of eye

a. sclerotic coat; *b.* choroid coat; *c.* retina; *d.* cornea; *e.* aqueous humor; *f.* iris; *g.* lens; *h.* suspensory ligament; *i.* ciliary muscle; *j.* fundus with vitreous humor; *k.* fovea; *l.* blind spot, and optic nerve.

an elastic curtain formed by an extension of the choroid coat, acts as the camera shutter, capable of increasing or decreasing the size of the pupillary aperture, thus controlling the amount of light which it admits into the chamber. The third lens, and the only one which is adjustable, is the so-called crystalline lens which is not crystalline, but an elastic capsule with many concentric layers, like an onion, 3.6 mm. thick at the center, enclosed in an integument and suspended directly behind the iris by the suspensory ligaments. These ligaments are controlled by the ciliary muscle, an extension of the choroid coat, and by their action alter the refractive power of the lens. According to Helmholtz, when the ciliary muscle contracts diagonally, the front surface of the lens is permitted to bulge outward; and when the muscle expands, the front surface of the lens flattens. The change in refractive power of the eye thus produced by accommodation, amounts to about 14 dioptries at ten years of age and steadily lessens with increasing years. Back of the crystalline lens lies the fundus, the large spherical cavity lined by the retina and filled with vitreous humor. Thus light reaching the retina has been refracted by all four media, cornea, lens, aqueous and vitreous humor, the final result being a sharply defined retinal image.

Changes in refractive power for near and far vision are brought about in human beings by the adjustment of the crystalline lens. In snakes the same effect is achieved by moving the lens forward and back; in sepia by lengthening the eyeball; and in birds by bulging the cornea. In human beings, at ten years of age, the near focus is 7 centimeters, at 60 years, it is 100 centimeters.

Common visual defects in human beings are the following: (1) Hypermetropia, in which the eyeball is too short, or the accommodatory action of the lens too weak to adjust to near vision; (2) Myopia, in which the eyeball is too long, or the accommodatory action is too strong to allow the proper flattening for far vision; and (3) Astigmatism, where slight differences in the radius of curvature of the cornea in meridians at right angles to one another or slight tilting of the lens occur.

The retina is not a homogeneous membrane. The region directly back of the center of the pupil is the central region of the retina — the fovea centralis, .1 mm. in diameter. The immediately surrounding region is the macula lutea, or yellow spot, 3 mm. in diameter, so-called because of its pigmentation. About 3 mm. to the nasal side of the posterior pole of the eye is the head of the optic nerve. The light sensitive structures are absent here, resulting in a blind spot 1.8 mm. in diameter opposite this region. At 25 cm. in front of the blindspot, a five-cent piece is invisible.* Finally, the cellular structure of the retina undergoes certain changes between center and periphery.

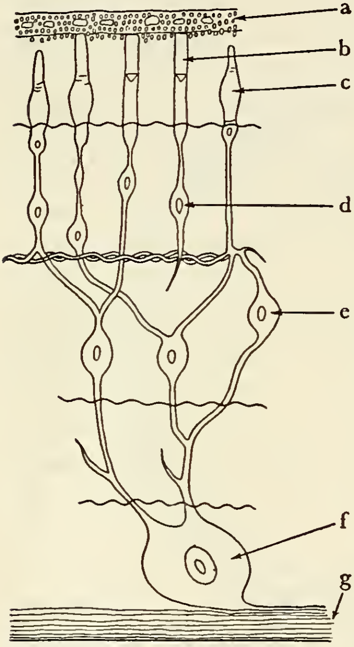

Fig. 3. Minute structure of retinal layers

a. epithelial cells; *b*. rods; *c*. cones; *d*. nuclear layer; *e*. bipolar layer; *f*. ganglion cell; *g*. axons forming optic tract.

HISTOLOGY OF THE RETINA

The retina, which has a thickness of .1 to .4 mm., consists of a series of layers, arranged one in front of another. Since the light-sensitive layer is the furthest back, it is necessary for rays of light to pass through all the other layers to reach it, and the intensity is thereby considerably reduced. This last layer consists of the rods and cones, arranged side by side. There are millions of these structures in this layer. There are 138 cones per hundredth of a millimeter on the average. Back of the rods and cones the choroid coat forms a supporting and nourishing background containing the pigmented epithelium, which functions in light and dark adaptation of the retina. Since each rod and cone is a specialized part of a nerve cell, the layer of cell bodies lies immediately in front of the rod and cone layer. This is known as the nuclear layer. In front of this lies the layer of bipolar cells, which receive and pass on the impulses from the nuclear layer to the large ganglion cells lying in front of them. Each ganglion cell receives impulses from many bipolar cells, so that the stimulations from several rods or cones are concentrated on a single ganglion cell. The axones of these ganglion cells pass in front of them to the point where the optic nerve leaves the retina, and they form the bundle of fibers of which the optic nerve is composed. There are 480,000 fibers in the optic tract. They thus form a thick mat of fibers covering the front surface of the retina.

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* Some recent research casts doubt on the total blindness of the blind spot.

The distribution of rods and cones is not uniform over the entire retina. The fovea centralis and rod free area contain no rods, only cones. Immediately outside of this area the distribution is more evenly divided. As the periphery is approached, the cones become infrequent relative to the rods, until, at the extreme periphery, almost no cones, only rods, are found.

According to the Von Kries theory, the rods function in brightness vision while the cones contain the mechanism for color vision. Certain anatomical facts support this theory, when correlated with psychological facts. Below are listed a number of correlated facts, the first substantiating the general theory that the rods and cones are the light sensitive structures while the rest support the special theory of Von Kries.

ANATOMICAL	PSYCHOLOGICAL
1. Congenital absence of rods and cones	Blindness
2. Rod-free fovea	Foveal night blindness
3. Cone-free periphery	Peripheral color blindness of normal eye
4. Congenital absence of cones	Color blindness
5. Predominance of rods and paucity of cones in bats, moles, owls, mice	Good night vision and poor day vision in these animals
6. Predominance of cones in birds	Vice versa
7. Action of visual purple in dark adaptation is confined to rods	Dark adaptation increases brightness vision, but not color vision

Certain structural, chemical, and electrical changes occur with exposure of the retina to light. The pigment granules of the epithelium called rhodophyllin migrate forward about the base of the rods and cones, and the cones contract. The visual purple or rhodopsin at the base of the rods bleaches white within ten seconds after exposure; in darkness its color is restored by contact with the pigmented epithelium. The regenerative process requires from ten to twenty minutes. Light increases the acidity of the retina. On exposure to light the retina undergoes an electrical change which shows up on a galvanometer as a negative followed by a positive variation in the "current of rest." All these changes are consensual, i.e., they occur in both eyes when one eye is closed.

In consideration of these facts, four theories have been advanced as to the manner of stimulation of the rods and cones, viz.: (1) the mechanical, (2) the thermal, (3) the electrical, and (4) the photochemical, which is most widely accepted.

THE EXPERIMENTAL FACTS OF LIGHT AND COLOR VISION

From the psychological side visual phenomena fall into two large classes — chromatic and achromatic sensations. The achromatic sensations vary with reference to one dimension only — that of brightness; whereas the chromatic vary in three directions, hue, saturation, and brightness.

There is no one-to-one relation between the characteristics of the physical stimulus and the resulting characteristics of the sensation. For example, in general, a light ray containing a mixture of all spectral wave lengths, i.e., heterogeneous light, gives rise to an achromatic sensation, while rays of one wave length, i.e., homogeneous light, produce characteristic chromatic sensations. Yet there are many other factors, presumably of a physiological nature, which enter into the determination of the chromatic or achromatic character of the experience. It is necessary to know certain things (a) about the stimulus, and (b) about the present and previous conditions of the retinal area stimulated. The more important of these are given below: —

Nature of the Stimulus

1. *Duration of the stimulus.* — Any light stimulus exerts an effect on the visual mechanism relative to its duration. If it acts on the retina for a very short period, it will arouse only an achromatic response, because the temporal threshold for color is higher than for brightness. If it acts on the retina for a very long period it will cease to arouse a chromatic response and will produce only brightness. There is an adaptation of the retina to continued stimulation by one wave length.

2. *Strength of the stimulus.* — A light stimulus acting upon the retina must attain a certain intensity before it will arouse any response whatsoever. This is called the *achromatic threshold* because only brightness, not hue, is produced at this level. When the intensity of the light stimulus is further increased it ultimately reaches the *chromatic threshold* and arouses hue. The difference between this and the achromatic threshold is that whereas the achromatic is absolute, the chromatic differs with the wave length of the light, being high for red, yellow, and violet, and lower for green and blue. The interval between the achromatic and chromatic thresholds is known as the photochromatic interval (red has none). It may be represented thus: —

Stimulus:	Low Intensity	Photochromatic Interval	High Intensity
Response:	Invisibility	Achromatic vision	Chromatic vision

If, now, the intensity of the stimulus be increased very greatly it will ultimately fail to arouse hue any further, but will arouse only brightness. It has exceeded the *upper chromatic threshold.* Thus any wave length will be seen as white light if it is intense enough.

3. *Rate of succession.* — If a light stimulus of short duration is repeated, the resulting sensation will depend on the frequency of succession of the stimulations. If the stimulations are relatively infrequent, they will be experienced as discrete. If they are increased in frequency, a point will

be reached where they will be seen as a continuous flicker, the apparent brightness of which will be greater than that of the discrete experiences. Now, if the stimulations are still more frequent, they will no longer appear separate but will blend into a continuous sensation, the brightness of which is less than that of either the flicker or the discrete sensations. Talbot and Plateau, investigating this relationship, found that the brightness of the resulting impression is equivalent to the mean brightness throughout the period of stimulation. This is known as the Talbot-Plateau Law.*

Conditions of Retinal Area Stimulated

It is equally important to know the conditions of the retinal area stimulated. The following facts are necessary: —

1. *Character of preceding stimulation.* — The sensation produced by a given stimulus is a function of the hue, the intensity, and the length of the preceding conditions of stimulation of that area. These are sometimes spoken of as fatigue effects and include adaptation, successive induction, et cetera.

2. *Character of surrounding stimulations.* — The response obtained from a given area is a function of simultaneous stimulation taking place in neighboring areas.

3. *Stimulation of other retina.* — If the other retina is being simultaneously stimulated it will affect the responses of the given retina.

4. *Part of retina stimulated.* — The nature of the chromatic as well as achromatic responses will be a function of the part of the retina stimulated. A chromatic stimulus at normal intensity will produce an achromatic response on the extreme periphery, though Baird reports weak color sensations from very strong peripheral excitations.

5. *Size of retinal area stimulated.* — Even a chromatic stimulus will elicit an achromatic response provided the area of stimulation is sufficiently restricted, or provided the stimulus object is sufficiently distant from the retina. Probably the limit of size of area which will elicit a brightness re-

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* See: Parsons, H. *An Introduction to the Study of Color Vision.* New York: G. P. Putnam Sons, 1915, p. 92.

sponse is determined by a single rod or cone, but color requires a considerably larger area at ordinary intensities.

I. INTERRELATIONS OF HUE, SATURATION, AND BRIGHTNESS

The Spectrum

1. *Hue differences.*—An examination of the solar prismatic spectrum brings out certain important facts regarding the interdependence of the visual attributes of hue, saturation, and brightness. First, we notice that the spectrum consists of a series of different hues with gradual transitions between, from the longest visible wave lengths, which give red, to the shortest, which give violet. Four of the hues stand out as distinctively unique: red, yellow, green, and blue. Orange is obviously a mixture of red and yellow in which the relative proportions of red and yellow gradually shift from a predominance of red to a predominance of yellow. Yellow-green and blue-green are similar blends. Violet is a blend of blue and red in which blue predominates. The spectrum ends abruptly at violet; but if we should extrapolate a short series of steps beyond violet in which the red component is progressively increased, we should eventually reach red again, through purple. Purple is a nonspectral mixture of red and blue. Thus the *corrected* spectrum is a continuous circle, returning upon itself. Nine principal hues appear in it, four of which seem unique and unmixed. From these, all known colors can be produced with the help of white and black.

2. *Brightness differences.*—Beside the changes of hue, there is a decided change of brightness from end to end of the spectrum. Thus, in daylight illumination, the yellow region is the brightest by far and there is a falling off of brilliance in either direction from it. The relative brightnesses of the different parts of the visible spectrum are shown in the chart below. It is to be noted that this is not a function of the relative objective intensities of the different wave lengths, for they progressively decrease in strength from the long to the short end. It is rather to be explained physiologically as a difference in the excitability of the retina for

different wave lengths, and hence we may speak of an *intrinsic* brightness of different colors, irrespective of the *extrinsic* brightness based on the objective intensity of the wave. It is therefore obvious that the psychological attribute, luminosity~~, is~~ a complex resultant of two things — intrinsic and extrinsic brightness. Hereafter the term luminosity will be used for this resulting attribute. (Other names are brightness, brilliance, etc.)

3. *Saturation differences.* — A third difference that can be noted, in comparing the different parts of the spectrum with one another, is that the red is redder than the yellow is yellow, et cetera. Such differences are caused by the relative amounts of white light in the different colors, causing some to be purer than others. Thus yellow, since it has the most white light, is the least pure color and hence least *saturated.* It is possible by adding white light to any color to reduce its saturation to a point where its hue disappears entirely and it becomes a colorless gray. Such a color is said to be completely desaturated. But the same effect can be obtained by reducing the color's luminosity, or, in other words, adding black to it. Hence saturation and luminosity are interdependent variables.

4. *The scotopic spectrum.* — The characteristics of the spectrum which have just been described are true only for daylight illumination. At low intensities of retinal illumination certain very definite changes occur. These are attributed to a process in the retina, the physiology of which has been previously described, called darkness adaptation, whereby the sensitivity for brightness is increased some 4,000 times. Since this increase in acuity is for brightness but not for color, there is no color vision at low illumination. It becomes necessary, therefore, to distinguish clearly between photopic (i.e., daylight) vision, and scotopic (i.e., twilight) vision. Between these two illuminations certain shifts in the spectrum occur: —

The hues disappear, but at different intensities. Yellow and red become duller and disappear first. Green and blue become relatively more visible, and disappear at relatively lower intensities.

The luminosity of the different parts of the spectrum undergoes a decided shift, so that the brightest part moves in the direction of the short wave length end, to a point about opposite green. Figure 4 shows this shift, which is known as the shift of the luminosity curve, and the resulting curve is called the scotopic luminosity curve. Purkinje (1825) investigated these effects, which accounts for their name — "Purkinje phenomenon." They have important theoretical bearing on the Von Kries duplicity theory, and on our interpretation of the nature of luminosity. Hering has taken cognizance of this.

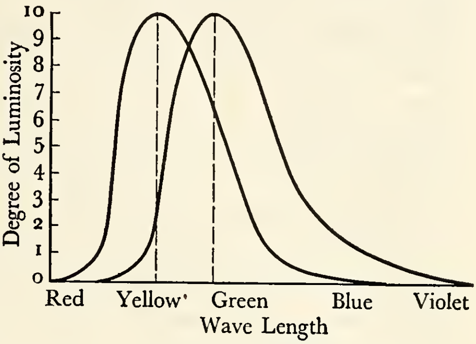

FIG. 4. Photopic and scotopic luminosity curves

After Troland, in Murchison's *Foundations of Experimental Psychology,* Worcester: Clark University Press. p. 63, Fig. 5.

Color Mixture. — In addition to the information gained through a study of the spectrum, regarding the dependent and independent variability of visual qualia, it is possible to supplement this by experimentally mixing the colors in every possible way. Various techniques for color mixing have been devised: (1) Pigment mixture, or physical mixture of the colored pigments; (2) Direct mixture of lights on a retinal area; (3) The rapid successive stimulation of retinal areas by the colors to be mixed, by means of rapid rotation of colored sectors; (4) Binocular color mixture by means of the stereoscope; and (5) Afterimage mixture. The third method is the most satisfactory for general experimental purposes. A motor rotator, or color mixer, on which colored

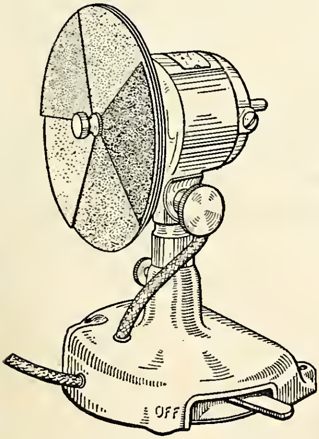

FIG. 5. Rotating color mixer

discs are mounted (in such a way that a given amount of each of the colors to be mixed is exposed) is revolved rapidly. The result is that the exposed areas of the retina are stimulated by the respective colors in such rapid succession that the effect is the same as though the lights were mixed directly.

Newton was the first to experiment systematically with color mixture (1704) and hence certain of the laws are known as Newton's Laws, though formulated later. The three main laws of color mixture, in accordance with Titchener's formulation, are as follows: —

I. For every color sensation there may be found an antagonistic or complementary one, which, when mixed with it in the proper proportions, gives gray; and, if mixed in any other proportions, gives a color sensation of low saturation having the hue of the stronger component.

II. The mixture of non-antagonistic color sensations produces a sensation of intermediate hue which can be found to lie between the two components on the spectrum, and whose saturation varies with the nearness or remoteness of the two components in the color series.

III. Called Newton's Law. If two color mixtures arouse the same sensation of light or color, then a mixture of these mixtures will produce the same sensation.

The first law has important implications for color theory, since it brings out the fact of complementariness, which shows a close interdependence of color experiences. The following chart of complements is adapted from Helmholtz:

COLOR		COMPLEMENT	
Red	656.2 μμ	Blue-green	492.1 μμ
Orange	607.7	Blue	489.7
Yellow	585.3	Blue	485.4
Yellow	573.9	Blue	482.1
Yellow	567.1	Indigo-blue	464.5
Yellow	564.4	Indigo-blue	461.8
Yellow-green	563.6	Violet	433

It is very difficult to obtain a standard chart of complements by the laboratory color mixing methods, since there are so many variable factors involved.

(1) The saturations of the component colors differ, and hence unequal proportions of the two must be used. The saturation of paper colors is very unstable, due to fading.

(2) The relative strength of different colors with respect to each other shifts with any change in the illumination. Hence, what is a complementary match, at one illumination, is not at another.

(3) Individual observers differ in the sensitivity of their retinae to the same colors. It is, therefore, rare that any two observers can agree on a complementary mixture.

(4) The angle of reflection, or "angle of incidence" of the light rays from the source of illumination to the color discs and thence to the eye determines their relative strength. Hence a match which is complementary from one point of view is not from another.

(5) Mixtures which are complementary in foveal vision do not remain so when viewed excentrically.

The relationship between the luminosities of the component colors and the luminosity of the resulting mixture is important. Ebbinghaus claims that the gray value of the mixture is equal to the sum of the gray values of the two components. This, however, has not been corroborated by others.

The second law of color mixture also shows an interdependence of color experiences, but not to the same extent as the first, since it is possible to distinguish the two components in a noncomplementary mixture. Orange is obviously red and yellow. But the gray of a blue-yellow mixture is not obviously blue and yellow.

The color resulting from the mixture of any two noncomplementary colors (with the exception of purples) can always be found on the spectrum, between the two components, but its saturation is not always equivalent to that of the corresponding spectral color. It is usually less saturated, and white light must be added to the spectral color to produce a match.

The third law of color mixture expresses the fact that colors behave the same quantitatively and qualitatively *in mixtures* as they do otherwise. Thus if a particular mixture of red and blue-green gives the same gray as a certain mixture of blue and yellow then a mixture of these two mixtures will give the same gray. To demonstrate this it is necessary to keep illumination constant; otherwise the proportions are disturbed.

The Color Triangle.—With the facts of color mixture before us we can now proceed to construct a geometrical figure which will properly express the relationships involved. Since hue, saturation, and brightness are so intimately related, the ideal figure would have to be in three dimensions. However, the relations of hue and saturation can be expressed in a plane figure, the shape of which will be the mathematical result of experimental findings. The pertinent facts are these: (1) All the hues can be produced from the mixture in proper proportions of three basic hues. (2) The spectrum has certain definite transition points within it, at which the continuity seems to be broken; these transitions are at red, green, and blue. (3) The degrees of saturation of the different spectral colors differ. (And these, in turn, differ from the saturations of mixtures of the primary spectral colors.) It is necessary to represent these differences in some manner as compared with an ideally perfectly saturated series. (4) Complementariness of hues remotely situated in the spectrum. (5) The spectral discontinuity between red and blue which can be completed by varying mixtures of red with blue, giving purple.

Figure 6, known as the color triangle, brings out these various facts. The outer perfect isosceles triangle represents the ideal saturation values. At the center lies white (gray). The distance from the center, then, represents the degree of saturation. At the three angles lie the ideally saturated primaries. Within the larger triangle is drawn the empirical spectral triangle along the perimeter of which are located the spectral hues. A dotted line joins violet and red, since the hues along it are extra-spectral mixtures. The saturation of each hue may be judged by its distance from the center of the triangle. If two hues are complementary, then a straight line drawn from one to the other will pass through the center; moreover by determining the distance of each component from the center it is possible to determine the relative amounts of each which, when mixed, will produce a neutral gray.

Yellow is seen to lie midway between saturated green and saturated red, and therefore to be a mixture of these two, but less saturated than either. Neutral gray is seen to lie on a straight line between yellow and saturated blue, but nearer yellow, for yellow is less saturated than blue.

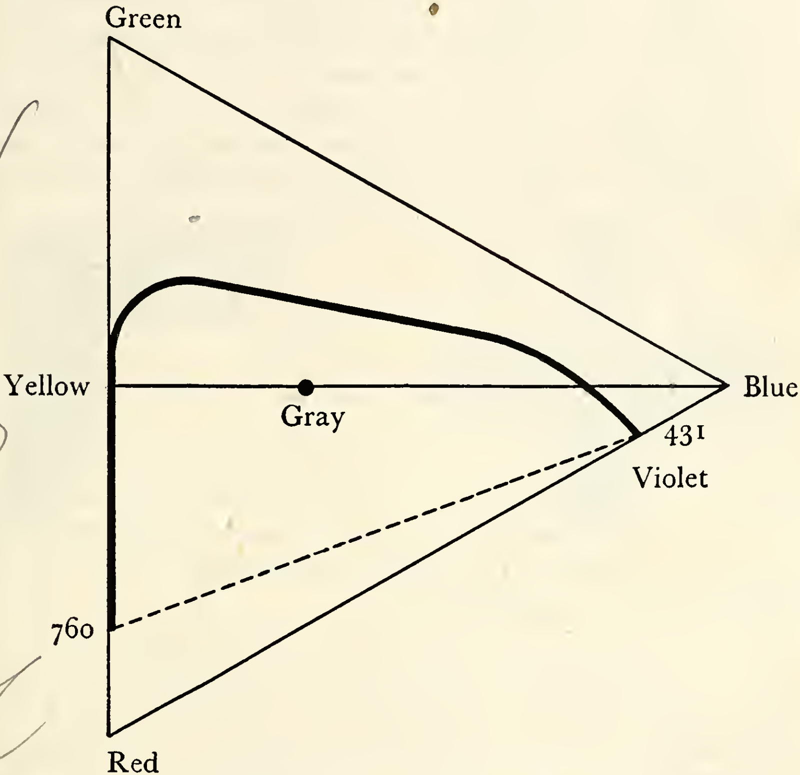

Fig. 6. The color triangle

The Color Pyramid. — The triangle neglects the third dimension of visual sensation — luminosity. The latter cannot lie within the same plane, but must be represented by a perpendicular to this plane, piercing the triangle at the center. Along this perpendicular would lie the continuum of grays from black at one end to white at the other. It would then be necessary to warp the plane of the triangle in such a way that the spectral luminosity of each hue would be properly represented by its distance from white.

No figure has been devised that adequately embodies all these features, but the nearest three-dimensional figure is the double pyramid or spindle, shown in Figure 7. The tipping of the base plane shows the relative luminosities of the colors by their nearness to the apex. Yellow is nearest, blue furthest away. This figure also demonstrates that desaturation may take place in three directions; by moving horizontally toward the central axis, i.e., by adding gray to the color without changing its brightness; by moving upward toward white; and by moving downward toward black. The main defect with the figure is in the arrangement of the colors in the base plane relative to one another. The figure is based on the Hering assumption of four primaries. This agrees with the introspective evidence that yellow is a psychologically unique and primary experience even though it can be produced by mixing red and green.

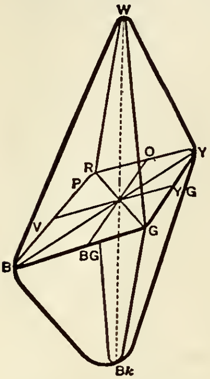

Fig. 7. The color pyramid

From Titchener in *Textbook of Psychology*, p. 63, Fig. 2.

II. SPATIAL INDUCTION OR CONTRAST

The visual experience resulting from the stimulation of a given retinal area is a function of the simultaneous and previous condition of stimulation of neighboring areas. The effect which these neighboring areas exert is known as spatial induction. When the effect results from simultaneous stimulation of neighboring areas it is called *simultaneous contrast*. When it results from previous stimulation of the neighboring areas, it is called *successive contrast*. No adequate explanation of the facts has yet been offered, though they are of considerable theoretical importance, since they show a spatial interaction of visual mechanisms. Spatial induction acts upon both *hue* and *luminosity*. It is strongest on first exposure.

Luminosity Effects.—A small area of light will appear brighter or less bright in proportion as the surrounding area is made dark or light. Thus a patch of gray paper appears darker on a white background than on a black. That the effect is reciprocal can be shown by the fact that at the line of junction between a white and a black sheet of paper, laid side by side, the white appears brighter and the black, darker. The effect becomes rapidly less in proportion to the distance away from the line of junction. The strength of the contrast effect is a function of several variables: the size of the inducing area, the size of the induction area, the ratio of intensities of the two areas, though not their absolute intensities; and the shape of the inducing area, as well as the location of the induction area on it, and the general contours. Gestalt psychologists have emphasized the dependence of the phenomena on contour as evidence of the influence of field properties. For example, in the accompanying figures, the white triangle in the black " L " looks brighter than that in the black cross because it is in the figure, not in the field.

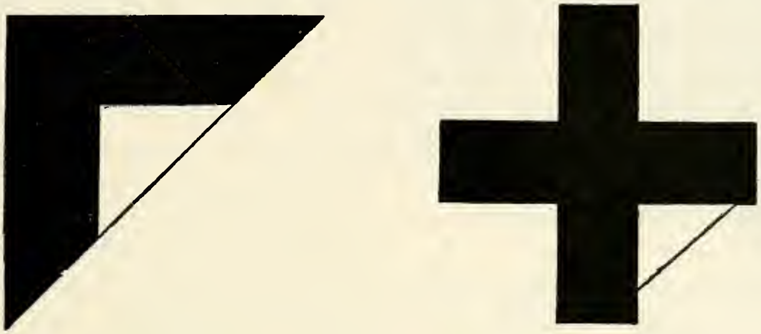

FIG. 8. Effect of contour on luminosity

Hue Effects. — If a small neutral gray area is imposed on a colored area, the gray area will be tinged with the chroma *complementary* to the inducing color. The strength of this induced chroma is a function of the following special factors: —

(1) The saturation of the inducing color. Hering reports that contrast increases with the saturation of the inducing field. Titchener reports the same. Not all observers agree.

(2) The luminosity of the inducing color. The contrast is greatest when the two areas are of equivalent gray value. Any

brightness contrast in either direction decreases the color induction.

(3) The shape and clearness of contours; the spatial proximity of the contrasting areas; and the relative size of the inducing and induction areas.

Methods of Investigation

(1) *The rotation method.* — Either brightness or color contrast can be demonstrated quantitatively with discs and color mixer in the following way: Revolve on one rotator a large and small disc of the contrast color (red, for example) with an intermediate gray ring between them (composed of black and white discs) whose brightness value has been equated with the red. Revolve on a second rotator a gray combination of the same brightness as the red to which has been added enough of the complementary chroma (i.e., blue and green discs) to produce a match with the gray ring on the first rotator. The amount of the blue-green necessary is a quantitative measure of the strength of the contrast.

This same method can be used to demonstrate brightness contrast. It can also be used to study the effect of systematically varying the saturation of the inducing color, and the relative brightnesses of inducing color and gray ring, on the strength of the contrast effect.

(2) *The background method.* — If a small area of gray be placed on a colored background and the whole covered with tissue paper, the contrast effect will be strong, due to the obscured contour. If two colored areas of complementary hue be placed beside one another, each color will be increased in saturation along the line of their junction, with a diminishing effect for remoter areas, proving that proximity is necessary to contrast.

(3) *The negative afterimage method.* — This brings out successive contrast effect. After gazing at a small gray disc in the center of a large colored disc long enough to secure an afterimage, project the image on a neutral gray background. The center of the image will have the complementary chroma. Brightness contrast can be similarly studied. It will be found that contrast effects are enhanced in the afterimage.

(4) *The illuminated compartment method.* — This method is useful for studying brightness contrast. A box, partitioned off by a screen into two compartments, a front and rear one, with a window between. The observer gazes into the front compartment. The compartments are independently illuminated with rheostat controls so that either can be varied systematically while the other is held constant. Illumination of the rear compartment brightens the windows, while illumination of the front compartment brightens the screen.

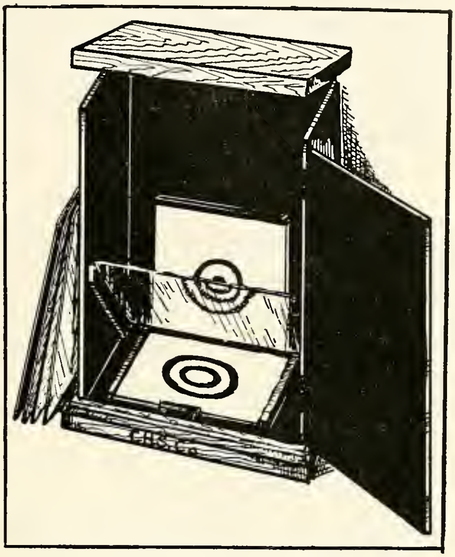

Fig. 9. Hering contrast box
Courtesy of C. H. Stoelting Co.

(5) *The mirror method.* — This was used by Hering. A picture of the apparatus is given in Figure 9. This gives the strongest effects of all. It is difficult to tell which is more saturated, the real or the contrast color.

III. TEMPORAL INDUCTION. — AFTERIMAGES

If an area of the retina has been stimulated for a short time (20 seconds) with light, and the stimulus is then withdrawn, certain effects persist in that area. These are called afterimages, and the process is known as temporal or successive induction. The nature of these afterimages bears a direct relation to the nature of the preceding stimulus. At least four different types of afterimage occur. (1) If the stimulus is achromatic light, under proper conditions it will be followed immediately by an image of the *same brightness* and detail as the stimulus, which will quickly vanish. This is called a *positive afterimage.* (2) Within a second or two after the removal of the achromatic stimulus, there will appear an image of the *reverse brightness,* i.e., black, which will persist a short time. This is the *negative afterimage.* (3) If the original stimulus is chromatic, it may immediately be followed by an image of the same hue, called the *homochromatic afterimage.* (4) Within a couple of seconds an image of the antagonistic or complementary hue will appear, and will persist for a short time. This is the most important of all for color theory, and is called the *complementary afterimage.*

DETERMINING FACTORS

THE factors which influence the exact hue, brightness, saturation, lag, duration, size, and recurrence of the afterimage are many. Most of them have been experimentally investigated, with fairly consistent results. The more important of these factors are the following: —

(1) *Nature of the stimulus.* — The brightness, saturation, size, and duration of the stimulus are important, as well as the hue. A bright light is more likely to give recurrent or intermittent afterimages of varying hue. The order of these has been investigated by Washburn, McDougall, and, recently, Berry. The relation of brightness, latency, and duration of the image to the brightness, duration, and size of stimulus was studied by Franz. His results in minimal stimulations are:

For 1/100 sec. exposure and 64 sq. mm. area, an intensity of 2/25 candle power.

For 1 sec. exposure and 4 sq. mm. area, 2/25 candle power.

For 1 sec. exposure, and 64 sq. mm., 1/100 candle power.

He found the latent period of the afterimage dependent on the time, area, and intensity of the stimulus, but not proportionally. The same was true of duration of the image. Size of image is related to the background against which it is projected. Retinal transfer effects, whereby a stimulus to one retina produces an afterimage in the opposite retina, are not entirely substantiated. The saturation of the image is directly related to the strength of the stimulus.

(2) *Nature of background against which the image is projected.* — The ideal background is a neutral gray. If the

background is lighter or darker, the brightness and saturation of the image are affected relatively. If the background is chromatic, the resulting hue will be a function of the mixture. Thus an afterimage of a red disc projected on a red background will appear as a desaturated area on the background; on a blue-green background it will appear as a more highly saturated area; on a yellow background it will produce a yellow-green and on a blue background a greenish blue.

If the eyes are closed and all light shut out, the afterimage is still visible against the dark gray. An afterimage of a white stimulus will cause a spot of black to appear in the field of the closed eyes. This is important because it shows black to be a true process, physiologically.

(3) *Part of retina stimulated.* — This follows the laws of zonal distribution of color sensitivity to be considered later.

Methods of Investigation. — For ordinary purposes, with constant illumination, the colored paper method of securing afterimages is satisfactory. The images may be projected against gray or colored backgrounds, or the dark field of the closed eyes. To secure afterimages of monochromatic colored lights, it is necessary to project the stimulus light through monochromatic gelatin filters in a dark room. To get recurrent images, the light must be relatively intense.

IV. ADAPTATION OR RETINAL FATIGUE

TEMPORAL or successive induction is often considered a fatigue phenomenon, though the rapidity with which afterimages appear belies this. A related phenomenon which is unquestionably due to fatigue effects is adaptation. It can be studied in two ways: (1) by flooding the entire retina with monochromatic light, or (2) by steadily fixating the gaze for several minutes on a restricted area of color. In the latter case, the optimum area is less than a centimeter in diameter.

By the former method it is possible to fatigue the eye to a given hue, e.g., red, so that a stimulus in that hue appears dark gray, and all mixed chromatic stimuli in which red is a component are distorted; purple becomes violet, yellow becomes green, etc.

By the latter method it is possible to make all the chroma disappear from a small colored disc and be replaced by gray. A light gray disc will completely disappear after it has been fixated for some time. Great care is necessary to prevent fixation from shifting and resting the fatigued area.

The method of flooding the eye with filtered chromatic light and selectively fatiguing it to all but one primary spectral color has been used to map out the range or extent of sensitivity to the different hues over the spectrum. The results by this method are:

Red — 760.6 to 551
Green — 593 to 484
Blue — 517 to 443
Violet — 454 to 397.5

V. ZONAL DISTRIBUTION OF COLOR SENSITIVITY

As has been suggested earlier, the retina is not uniformly equally sensitive to color. Achromatic stimuli are visible over the entire retinal field. The limits of this field are estimated to be, for daylight intensities of illumination, 90° along the temporal meridian, 60° along the nasal, 50° along the upper vertical and 70° along the lower vertical. The foveal rod-free area is relatively blind in scotopic vision, while the peripheral sensitivity is increased 40,000 times. In photopic vision, the central regions are more acute for form discrimination, but the periphery is more sensitive to moving stimuli.

Chromatic stimuli are responded to differently for different regions. There are roughly three concentric zones: the central zone is sensitive to all the hues; the middle zone to blue and yellow; and the outer zone only to achromatic stimuli. Usually the limits of red slightly exceed those for green and the limits for blue exceed those for yellow. Most color stimuli in passing from center to periphery undergo changes of hue in moving from one zone to the next. Those at the red end of the spectrum pass through yellow to gray while those at the violet end pass through blue to gray. The greens become yellowish before turning gray.

There are four specific hues which do not undergo any intermediate changes but pass directly into gray. These are known as the *Urfarben,* because they behave as primaries.

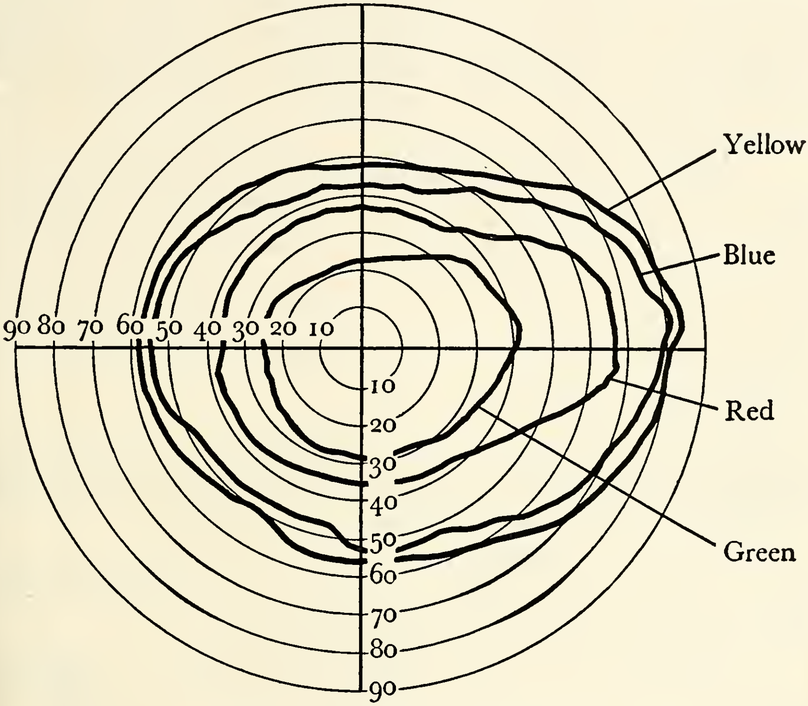

FIG. 10. The color zones

They are *Urroth,* a non-spectral purplish red; *Urgrün,* a blue-green; *Urblau,* an ultramarine blue, and *Urgelb,* a yellow. The zonal limits of *Urroth* and *Urgrün* coincide, and those of *Urblau* and *Urgelb* do also. The paired *Urfarben* behave as complementary hues in mixtures and Baird claims that they give gray when mixed in exactly equal proportions, though this is disputed.

DETERMINING FACTORS

THE extent and shape of the color zones vary with several factors. Among these are:

1. *The brightness and saturation of the stimulus.* — With increased strength of stimuli the zones are widened along all meridians. In fact, Baird found that with very saturated stimuli and good illumination all hues could be distinguished as far as the limits of the periphery. Parsons * formulates a law from Abney's data that "as the intensity diminishes in geometrical progression, the angle of field diminishes in arithmetical progression." In general, the photochromatic interval is greater for peripheral than for foveal stimulation.

2. *The area of the stimulus.* — There is a minimum area above which changes in size have no effect on the sensation; but below this minimum there is a proportional shrinking of the fields for every decrease in size of stimulus. Of course there is also a minimum area for visibility, which is larger for periphery than for fovea, in photopic vision, though in scotopic vision this is reversed.

3. *Duration of stimulus.* — It is necessary to stimulate the periphery much longer to get complementary images; and the fading of colors in peripheral vision follows a series of transitional steps, through yellow or blue to gray.

4. *Brightness of background.* — Fernald has demonstrated that the character of color experiences in the periphery is dependent on various achromatic conditions.

5. *Conditions of previous retinal stimulation.* — Fatigue, drugs, hysteria, etc., all influence the size of the zones. It is therefore evident from the foregoing facts that the zones are not spatially fixed limits with abrupt boundaries. The condition is rather that of gradually reduced sensitivity over a wide transitional zone. Figure 11 expresses this schematically. When any condition, such as fatigue or decreased illumination, etc., acts upon the retina as a whole to raise the threshold (represented by the horizontal line) then all the zonal limits contract. Thus the red-green zone contracts from extent "c" to extent "a." The blue-yellow zone contracts from extent "d" to extent "c." This is important in considering the color theories.

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* See Parsons, J. H. *An Introduction to the Study of Color Vision.* N. Y. G. P. Putnam's Sons, 1915, p. 79.

Figure 10 shows a map of the color zones for a normal subject with all factors held constant.

Beside the color shifts there is a shift of the spectral luminosity curve from fovea to periphery. Roughly this shift is slightly in the direction of scotopic vision, the reds becoming relatively darker grays and the greens relatively brighter. This is partly due to the fact that the periphery is poorly illuminated, being dependent upon indirect rays, and partly to the fact that with the loss of chroma, one component of luminosity has been removed.

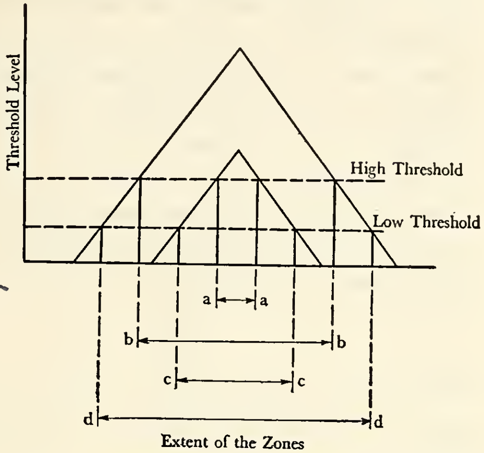


FIG. 11. Variation in extent of zones

Methods of Experimentation.—Various forms of perimeter are used, all involving the principle of a stationary arc, calibrated in degrees, which is held before the eye to be tested at a radius distance of 1½ feet. Either a small round color stimulus is moved outward along the arc while the eye is held stationary; or the stimulus is held stationary, directly in front, and the gaze slowly moves along the arc, following a guiding arrow. The arc can be adjusted to any retinal meridian.

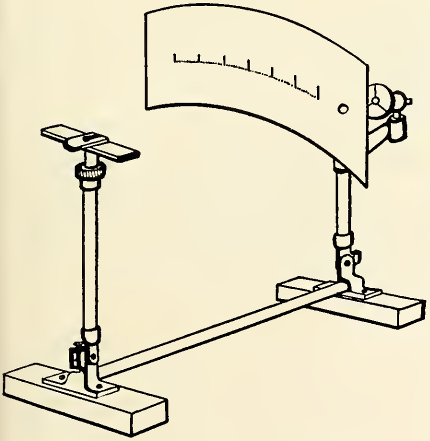


FIG. 12. Campimeter
Chicago type

The Carr campimeter uses a stationary stimulus, seen through an aperture, in the arc, which can be varied in size. It has the decided advantage of containing a rack for a motor color mixer so that any desired mixture of colors can be presented to the eye through the aperture, and saturation can also be varied at will.

In mapping out zonal limits the following procedure is followed. The observer first fixates the color and then moves his eye out along one meridian until the chroma disappears from the stimulus. When this point has been marked, he continues to the limit of visibility. He then fixes his gaze at the extreme outer limit of vision and then moves in along the arc until the color again appears. As a rule the movement from outward in gives a narrower zonal limit; hence an average of the two measures is taken.

VI. COLOR BLINDNESS

Considerable study has been made of color blindness because of its bearing on color theory. The main types are as follows: —

1. Anomalous trichromatism
    a. Protanomalous
    b. Deuteranomalous
2. Dichromatism
    a. Protanopic
    b. Deuteranopic
    c. Tritanopic
3. Monochromatism

Normal vision is said to be trichromatic because it is necessary to use *three hues* in producing all the others by mixture. The anomalous trichromats are like normals in this respect but their vision is relatively weak in the direction of either red or green. The former are called protanomalous, the latter deuteranomalous.

The dichromats can match every part of the spectrum by mixtures of *two* primaries. The first two classes have yellow and blue vision and lack green and red. The difference between them is that the protanopes are relatively blue sighted and the deuteranopes relatively yellow sighted. The spectrum of the protanopes is shortened at the red end. The regions of the spectrum occupied by red and green in normal vision are filled in by desaturated yellows and blues. These types are the commonest, affecting about 8% of the male population, and about 1% of women.

The third variety of dichromatism, the tritanopic, is rare, and is thought to result from disease. The subject is blind to yellow and blue. Troland states that the dichromats all have a colorless band in some part of the spectrum, at 492 for the protanopes, at 498 for the deuteranopes, and at 583 for tritanopes.

The monochromats have colorless vision. The spectrum is, to them, a series of varying gray values. The important theoretical point about them is that their spectrum corresponds to the scotopic rather than the photopic luminosity curve of normal persons. Their brightest spectral band is opposite green rather than yellow. This again demonstrates that luminosity is a combined effect of rod and cone vision, and that absence of color vision distorts the luminosity curve.

METHODS OF INVESTIGATION

THE difficulty in diagnosing cases of color blindness is that other cues beside hue can be successfully used by the subject, such as texture differences, differences in luminosity, saturation, and a familiarity with the color names which belong to different objects. Thus a color-blind person knows that grass is green, roses red, the sky blue. It is necessary to use tests in which all such cues are removed.

The Stilling Test. — This is the quickest, and for practical purposes best. A book of 15 color plates is presented to the subject. Each plate consists of a pattern worked out in spots of certain colors, varying in saturation and brightness. To the normal eye the pattern appears in the form of a given number, such as 25. To the color-blind eye it appears differently, depending on his type of defect. The Ishihara Test is a later modification of this.

Holmgren Wools. — This is a box containing three large test skeins, a green, a red, and a rose, and 125 small skeins of wool in several different hues, tints, and shades. The subject must sort in piles all those resembling in color each of the large test skeins.

The Hering Test. — An open box with eye tube through which the subject looks down into a square case. Into this case light is reflected through yellow, blue, red, and green glasses, which are slipped into hinged frames on the sides.

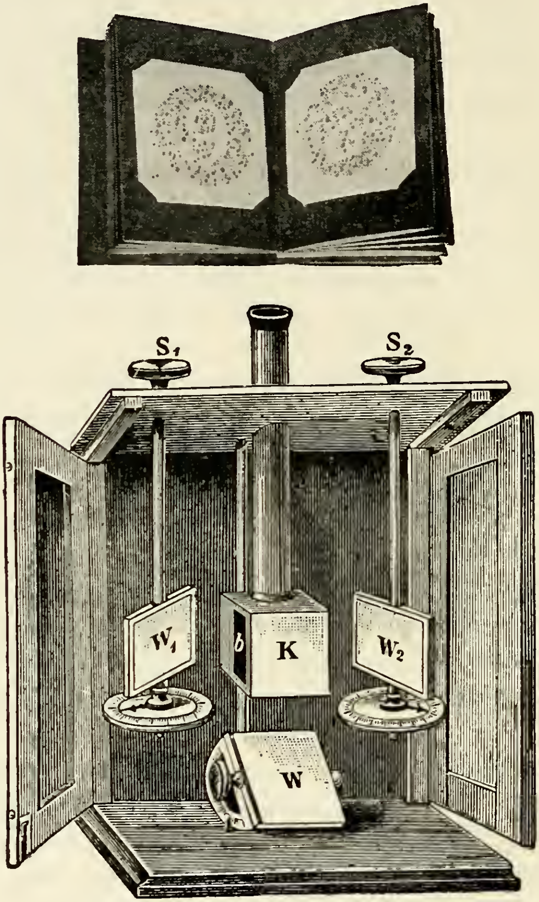


Fig. 13. Color blindness tests
Ishihara and Hering

Courtesy of C. H. Stoelting Co.

Any mixture of colors can be secured and saturation and luminosity can be systematically varied by manipulation of milk-glass reflectors at the sides and bottom.

VII. BINOCULAR EFFECTS

These are important because of their bearing on color theory. If such effects as achromatic complementary mixtures, contrast hues, and contrast brightness, are to be explained in retinal terms only, then binocular interaction should not occur. Yet the following have been observed: —

Binocular color mixture. — If, by means of a stereoscope, yellow is presented to one eye and blue to the other, the result is a rivalry in which some of the time one color or the other is seen alone, but more often a fusion occurs in which either neutral gray appears, or else a desaturated shade of one or other of the two colors. If non-antagonists are presented, they fuse into a mixed hue.

Binocular contrast. — Under proper conditions observers have reported that when one retina is exposed to a given color a contrast hue is induced in the other retina.

THEORIES OF COLOR VISION

The physiological and neurological data on color vision are very inadequate. The problem of devising a good color theory, therefore, is one of logic: to put together the psychological facts in a consistent system which will leave as few phenomena as possible unexplained. There are four major theories of color vision, the first of which, the Von Kries duplicity theory, is specific and applies only to the special problem of the differentiation between rod and cone vision, while the other three are general color theories, the Young-Helmholtz, the Hering, and the Ladd-Franklin theories.

The Von Kries Theory. — This states that rod vision is achromatic scotopic, while cone vision is photopic and hence both chromatic and achromatic. The rods are assumed to undergo scotopic adaptation, or increased sensitization for low illumination, through the action of the visual purple, and to respond better to short wave lengths. The cones, having a much higher threshold, are assumed to be unaffected by the visual purple and hence to undergo no increase in sensitiveness in dark adaptation, reacting only to daylight luminosities. Certain physiological evidence in support of the theory has already been given. The following psychological facts are explained by it:

(a) The Purkinje phenomenon, or shift in the luminosity curve toward the short-wave-length end of the spectrum in twilight illumination, for all regions of the retina except the fovea.
(b) The protochromatic interval, or colorless vision in twilight, for short wave lengths, but not for red.
(c) Foveal night blindness.
(d) No achromatic threshold for the fovea.
(e) Lack of color vision in the color blind, and a scotopic luminosity curve.
(f) Night blindness in subjects whose rod functioning is disturbed.
(g) Achromatic peripheral vision in daylight illumination.

A rival theory assumes that the rods function in short-wave-length and the cones in long-wave-length vision, rather than in achromatic and chromatic, respectively; but the evidence is insufficient.

The General Theories. — Any theory must account for both the mutual independence and mutual dependence of the color qualities in terms of some corresponding structural or functional independence and dependence of mechanisms located either in the retina or nerve tracts. For example, the fact that the simultaneous stimulation of yellow and blue gives gray argues for mutual dependence of these two antagonistic processes, whereas the fact that red and yellow, when simultaneously aroused, give an orange, in which both components are recognizable and are not lost in the mixture, argues for the mutual independence of these two processes.

Any theory must explain the interrelations of hue, saturation, and brightness, or, in other words, the color triangle.

Any theory should, on the one hand, account for the fact that mixtures of *three* hues are sufficient to produce any known hue; and, on the other hand, explain the subjective uniqueness or primariness of *four* hues — red, green, blue, yellow.

Any theory should harmonize the various grays. There is the white resulting from mixing all wave lengths; the gray of complementary mixtures, monocular and binocular; the gray of adaptation; the gray of intense monochromatic stimulations; the gray of twilight illumination; the gray of peripheral vision; the gray of closed eyes (which is not black); the white afterimage of black; and the gray of color-blind eyes.

Any theory should account for the differing luminosities of the different colors, and the Purkinje shift.

Any theory should account for the black-white series, and especially for black, which is the absence of an objective stimulus.

In addition, all theories should explain the special phenomena of contrast, afterimages, color zones, the kinds of color blindness, and binocular effects. With these requirements in mind, we can evaluate the three major theories.

The Hering Theory

Assumptions. — There are six elementary qualities: black, white, and the four *Urfarben* — red, green, blue, yellow. These are explained by the existence, in the retina, of three different independent substances each of which can be excited in two different ways, such that either anabolism or katabolism is initiated. Since these two processes are mutually exclusive, the antagonism of complementary colors is explained by assuming that they represent antagonistic processes in the same substance. Hence the three substances are the red-green, the yellow-blue, and the white-black. Katabolic excitation arouses in the three substances respectively red, yellow, and white. Anabolic excitation gives green, blue, and black. Black is a color but has no external exciting stimulus. It occurs automatically as an expression of the vital activity of the retina. All wave lengths stimulate white but with different intensities, according to the spectral luminosity curve. Each of the four chromatic processes is aroused by a *limited range* of wave lengths, but with unequal intensity. Yellow and blue and blue and green ranges overlap but each has an exclusive set of wave lengths which excite only it. Red has no such exclusive range.

The intensity limen for white is *lower* than for the chromas; hence the photochromatic interval between the achromatic and chromatic thresholds. The relative limen of the chromatic processes varies with the wave length.

Phenomena Explained

(a) *Complementary relations* are explained in mixtures by the mutual exclusiveness of anabolism and katabolism, when aroused in the same substance. Thus, if yellow and blue are simultaneously excited, they cancel one another. The resulting gray is due to the stimulation of the white process by those wave lengths. The antagonism of white and black should cause them to cancel each other in mixtures, yet gray is the result. This is a serious weakness in Hering's theory.

Non-complementary mixtures are mere spatio-temporal contiguities of non-interacting processes in different substances. Hence such mixtures are not complete fusions.

The complementary relation in afterimages is due to the tendency for a substance automatically to regain metabolic balance. Thus, if red-green is continuously stimulated anabolically, we see green; but when the stimulus is removed, katabolism automatically sets in and we see a red afterimage. A process excited by an external stimulus is called allonomous; one set up automatically to regain metabolic balance is called autonomous.

Complementary relations in the phenomenon of contrast are explained by assuming that metabolic processes aroused in substances in a given area induce antagonistic metabolic processes in substances in neighboring areas. Thus, if the yellow-blue substance in a given area is excited anabolically, so that blue is seen, then the yellow-blue substance in neighboring areas will be autonomously excited katabolically and yellow will be seen there. The exact mechanism for this is not explained by Hering.

(b) *Color zones* are explained by assuming the substances to be distributed in zones over the retina. The changes in hue which all colors except the *Urfarben* undergo when moved peripherally are due to overlapping of stimuli. The variations of zonal limits with intensity and size differences of stimulus and with fatigue and hysteria must be explained by assuming that the intensity limen of a substance gradually increases near its zonal limits.

(c) *Intensity changes.* The reason why all chromas change into a specific gray is that the white process has a lower limen and the degree of excitation of it is a function of the wave length. Hering does not explain the Purkinje phenomenon, but he could, by assuming that the degree of excitation of white by different wave lengths varies with the absolute intensity of illumination.

(d) *The chromatic shifts* which a color stimulus undergoes in adaptation would illustrate the differences in threshold of different colors.

(e) *Binocular complementary mixture* could be accounted for by assuming the presence of color substances in the optic tract, but how explain binocular rivalry? And why rivalry between non-complements if they cannot interact?

(f) *Color blindness* is assumed to be due to an anatomical defect in one or two of the three kinds of substances. Since there is no black-white blindness, Hering would have to assume that this substance is never affected. The other kinds would then be accounted for, provided the substitutions which occur were explained by the overlapping of the range of stimuli. But the two forms of substitution in red-green blindness would be unexplained.

(g) *Hering* could make his anabolic and katabolic processes agree with the facts of electrical polarity in the retina (already discussed) by substituting red, blue, and white for red, yellow, and white, as the katabolic processes.

(h) *A major defect* in the theory is the choice of primaries which are not psychologically simple — *Urroth* and *Urgrün,* for example.

The Young-Helmholtz Theory: proposed by Young and adapted by Helmholtz

Whereas Hering placed more emphasis upon the physiological and psychological, Young and Helmholtz stressed the physical side.

Assumptions. — There are three elementary qualities, each correlated with a specific substance or end organ. They are carmine red, yellow green, and ultramarine blue. These substances are independent and non-interacting, so that mixtures are mere spatio-temporal juxtapositions. Each substance is stimulated by waves of all lengths, but the intensity of the effect varies with the wave length. Hence there is overlapping of stimuli. See Figure 14. Equal stimulation of all three substances gives gray; unequal stimulation gives one chroma. In the absence of external stimulus, the organs do not function and black results. For Helmholtz, then, black is not a true color experience as for Hering.

Phenomena Explained

(a) *Color mixture.* Every wave length stimulates all the substances, hence every hue is a mixture, and the differences are due to the different relative intensities of the components. Equality of intensities gives gray. Black is zero, and the gray series is an intensity series. Complementary colors give gray because they involve an equal stimulation of all three substances. Hence every gray could be analyzed into chromatic complements. Since a chroma results from relative inequality of intensity of stimulation of the different substances, its saturation would be determined by the amount of the unequal chromatic residuum after the three equal intensity components had united to give gray.

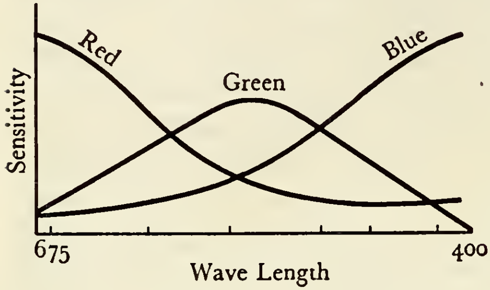


FIG. 14. Relative sensitivity of the different color substances to the different wave lengths

(b) *Afterimages* are due to fatigue of the given substance, causing a relatively greater excitability for its complement. The afterimage of white light is therefore a flight of colors. The gray afterimage of black cannot be explained, nor the black afterimage of gray except as relativity phenomena.

(c) *Contrast* is explained by resorting to an extraneous theory of "unconscious inference." First we tend to fill in small gaps in the exposure field, with the color of the field. Then, to compensate for this, we reverse it to the complementary color. This practically amounts to no explanation.

(d) *Color zones* are unexplained. Since gray results from equal stimulation of colors, then all color substances must be present in the periphery to give peripheral gray. Then, usually, colors should be seen there, because the substances would not always be equally excited. Otherwise, *Urfarben* should undergo color shifts and foveal whites should appear colored at the periphery.

(e) *Color blindness.* Helmholtz explains color blindness as lack of one or more substances, and substitutions are due to overlappings of stimulation. But then the totally color-blind should not see gray; and types of color blindness should exist which do not — for example, green-violet blindness.

The chief defects of the Helmholtz theory, then, are: —

(a) The difficulty with gray of color blindness, of peripheral regions, scotopic gray, gray from mixture of black and white, and the concept of black as void.

(b) The lack of subjective simplicity in his primary qualities, and the fact that yellow, which he considers a mixture of red and green, is psychologically simple.

(c) The inability to give a relevant account of simultaneous contrast.

(d) The lack of interaction between substances, which would be necessary to produce such unitary experiences as the gray of complementary mixtures.

The Ladd-Franklin Theory

This theory attempts to reconcile the two preceding theories in a single system which avoids the pitfalls of both. Ladd-Franklin's theory is a genetic theory. She assumes that color vision is a development from a primitive stage of colorless vision. A single photochemical substance is present in both rods and cones; but in the rods it is still in its primitive undifferentiated state, and responds, as a whole, to light stimulation of any wave length or combination of wave lengths, giving a sensation of gray. This primitive type of vision is therefore present in the extreme periphery where rods predominate. In the cones, occupying the regions inside this outer zone, further development has caused a differentiation of the gray molecule into two components, one of which reacts to the short waves with the sensation of blue, the other to the long waves with yellow. And in the central region of the retina the yellow component has been still further split into a red sensitive and a green sensitive component. Now if red light acts on the red-green-blue molecule a sensation of red results, due to its partial decomposition. And if both red and green light act on the molecule simultaneously the red and green components decompose and reunite in their primitive form to give yellow. But if both yellow and blue light simultaneously act on the yellow-blue molecule, equally, there is complete decomposition of the photochemical substance and gray results. Black is due to the vital activity of any of the molecules. Hence there are six primary colors, black, white, blue, yellow, red, and green, associated with three different molecules, one of which gives white and black; another gives blue, yellow, and black; and a third gives blue, red, green, and black, when partially decomposed; and all give gray when completely decomposed.

Processes in any molecule tend automatically to maintain equilibrum. Hence if the yellow-blue molecule is stimulated by blue light, causing the blue component to decompose, then the genetically related process is automatically stimulated and yellow is seen as an afterimage.

Phenomena Explained

(1) Complementary mixtures have been explained. All other mixtures would be mere simultaneous impressions without chemical combination. Complementary afterimages have been explained. Complementary contrast effects are accounted for by assuming that the partially decomposed molecule is unstable and floats to neighboring areas of the retina.

(2) The subjective simplicity of yellow, in spite of its mixed composition, is adequately explained by assuming the yellow process to be a genetically prior form of the red-green process.

(3) Color zones and achromatic peripheral vision are explained developmentally, provided leeway is left for shifting of zones through altered intensity thresholds.

(4) Color blindness of the achromatic and red-green sorts is explained as a primitive condition of color vision; but the rarer tritanopic dichromatism or yellow-blue blindness is

not, since red and green vision could hardly exist in the absence of their genetic antecedent, yellow.

(5) Binocular effects are unexplained.

(6) The Purkinje phenomenon is accounted for by action of the visual purple, thus: — The degree of intensity of stimulation determines the amount of bleaching of the purple. This affects the relative sensitivity to stimulation, or intensity, of the various processes. Hence there is a shift in the intensity ratio of the various chromas with changed illumination.

(7) The various grays are harmonized by assuming a common basis for peripheral gray, gray of low illumination, complementary gray, and color-blind gray, in terms of a primitive substance, with a low threshold.

Comparison of the Theories

All three theories attempt to account, on the one hand, for the facts pointing to mutual interdependence or *interaction,* and, on the other, for the facts showing independence of action of the different processes. Helmholtz stresses the fact that all the known hues can be described in terms of three variables which correspond to monochromatic spectral wave lengths. He therefore makes these his retinally independent *noninteracting* primaries; and in so doing fails to account for the simplicity of such mixtures of these as yellow and white. Hering, ignoring the preceding fact, is impressed by the antagonism of certain colors, in mixture, in after-images, etc., and by the pairing of these hues in zonal distribution, and in color blindness. He is also interested in the uniqueness of yellow and white and the fact that there are four subjectively unique primary chromas. He therefore postulates three pairs of primaries and thus achieves retinal interaction between complements and independent action of non-complements. Ladd-Franklin is interested both in trireceptorism (Helmholtz) and in tetrachromatism (Hering) and therefore combines them in a genetic theory. There are thus fewer objections to her theory than to either of the others, if we ignore the facts of binocular mixture. Hecht, however, believes that the possibility of binocular mixture proves that color sensations are problems of brain physiology and that we must appeal to central processes to explain their peculiarities rather than to retinal photochemical interaction. He would therefore postulate three independent end organs, each sensitive to all wave lengths, but one having its maximum sensitivity for blue, another for red, and a third for green.

REFERENCES

Baird, J. W. Color sensitivity of the peripheral retina. Carnegie Institute Publ., Washington, D. C. Reprint, 1905, p. 80.

Berry, W. Color sequence in the afterimage of white light. *Amer. J. Psychol.*, 1927, 38, 584–96.

Collins, Mary. Color Blindness. New York: Harcourt, Brace & Co., 1925.

De Silva, H. R., and Weber, A. The responsiveness of the blind spot. *J. Exper. Psychol.* 1932, 15, 399–415.

Ebbinghaus, H. Theorie des Farbensehens. *Zeitschrift f. Psychol. u. Physiol. d. Sinnesorg.*, 1893, 5, 145–237.

Fernald, G. M. The effect of achromatic conditions on the color phenomenon of peripheral vision. *Psychol. Monog.* 1909, 10, 91.

Franz, S. I. Afterimages. *Psychol. Monog.*, 1899, 3, 59.

Hecht, S. The nature of the photoreception process, in *The Foundations of Experimental Psychology,* ed. by Murchison. Pp. 216–272.

Helmholtz, H. Physiological optics. Translated from 3rd German edition. Rochester, Optical Society of America, 1924.

Hering, E. Zur Lehre vom Lichtsinne. Wien, Gerold's Sohn. 1878.

Hering, E. Ueber die Theorie des simultanen Contrastes von Helmholtz. *Arch. f. d. ges. Physiol.*, 1887, 41, 1–29; Eine Vorrichtung zur Farbenmischung, zur Diagnose der Farbenblindheit und zur Untersuchung der Contrasterscheinungen, (same journal) 1888, 42, 119–144.

Hering, E. Ueber das sogenannte Purkinjesche Phänomen. *Arch. f. d. ges. Physiol.*, 1895, 60, 519–542.

Ladd-Franklin, C. Color and Color theories. New York: Harcourt, Brace. 1929.

McDougall, W. The sensations excited by a single momentary stimulation of the eye. *Brit. J. Psychol.*, 1904, 1, 78–113.

Titchener, E. B. A textbook of psychology. New York: Macmillan, 1921, p. 68.

Troland, L. T., in Murchison's *Foundations of Experimental Psychology,* Chap. 4, Vision. Worcester: Clark Univ. Press, 1929.

Von Kries, J. Ueber die Funktion der Netzhautstäbchen. *Zeitschrift f. Psychol.*, 1896, 9, 82; 12, 1; 13, 242.

Washburn, M. F. The color changes of the white light afterimage, central and peripheral. *Psychol. Rev.*, 1900, 7, 39–46.

CHAPTER III

AUDITORY PROCESS

NATURE OF THE ADEQUATE STIMULUS

THE adequate stimulus to audition is the sound wave. This is typically the vibration (i.e., alternate rarefaction and condensation) of the molecules of air surrounding us. However, these molecular vibrations may occur in any substance, solid or liquid, as water. The source of the molecular disturbance thus propagated through space is the molar vibration of some sounding body, such as a tuning fork. There are certain important characteristics of such vibrations.

They are periodic like the vibration of a pendulum, following the laws of simple harmonic motion. Periodic vibrations produce the simple tones of a definite pitch, depending on their frequency. The frequency of vibration of a sounding body is a function of certain things: (1) It is inversely proportional to its length; (2) it is inversely proportional to the square root of its mass or thickness; and (3) it is directly proportional to the square root of its tension. The average human ear is sensitive to frequencies between a lower threshold of 24 to 30 per second and an upper threshold of 20,000 double vibrations per second. Musical tones have frequencies lying between 32 and 4,096 vibrations per second. Aperiodic vibrations do not have pitch, because of their variable frequency; they produce noises.

They have a certain amplitude, determined by the maximum displacement of the body from its undisturbed position. This determines the intensity of the sound.

The tuning fork, struck softly, vibrates only as a whole and hence emits only one fundamental frequency; but most sounding bodies vibrate in various fractional parts or segments as well and hence emit, in addition to the fundamental, several partials of higher frequency. These bear to the fundamental frequency the ratios 2, 3, 4, 5, etc., to 1. Such a series is called a harmonic series. The mathematical theorem describing this relation between a complex periodic vibration and its simple harmonic components was published by Fourier in 1822, and is known as Fourier's Theorem.

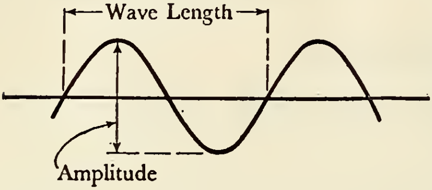


Fig. 15. Schematic representation of sound waves

The Sound Wave. — The vibrations of sounding bodies are transmitted through air as alternate condensations and rarefactions of the air molecules. One such alternate rarefaction and condensation constitutes an air wave. Figure 15 expresses the relation graphically. It is called a simple sine wave. The point of highest condensation is called the crest and that of the lowest, the trough. The vertical distance from crest to trough represents the amplitude; the horizontal distance from trough to trough represents the length which of course is inversely proportional to the frequency. Sound waves travel at a rate of 330 metres per second under standard atmospheric conditions. Their speed in water is over four times as great. They are reflected and refracted. Since the rate at which air transmits waves is a function of its density, sound waves will be refracted in the direction of the denser air. An example of reflection, on the other hand, is the echo which results from air waves being projected against a reflecting surface.

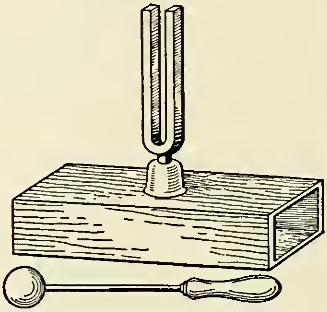


Fig. 16. Tuning fork

Interference. — Sound waves may be emitted from several bodies simultaneously. These combine into a single composite air wave, which is nonpendular, as in Figure 17. If the frequencies of two component waves are only slightly different the crests of the two will coincide at regular intervals, giving a reinforcement of the tone; and halfway between these intervals the crest of one will coincide with the trough of the other so that the two cancel each other and no sound is heard. See Figure 17.

The resultant effect of the two components is that, instead of a series of uniformly strong waves producing a steady note, we get a series of waves whose amplitude alternately increases and diminishes, causing the sound to alternately swell and lull. This is called beating and the swells are called beats. If the vibratory frequencies of the two waves differ by only one vibration per second, then the beats will occur once a second; or, in general, the number of beats which two waves make will be equal to the difference between their respective frequencies, or h—l.

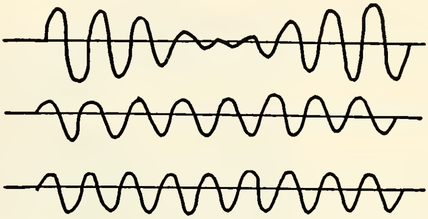


FIG. 17. Interference of sound waves

Resonance. — The significance of resonance in auditory theory makes a brief mention of the physical phenomenon necessary. If two tuning forks of the same vibration frequency are placed at some distance from each other and one is sounded and damped, the other will be heard to continue the note. It is said to vibrate sympathetically, or resonate the tone. The resonator reinforces the amplitude of the original tone, especially if the two bodies are in contact. Thus if a tuning fork be sounded free in the air, its tone is weak, but if it is mounted on a wooden box of the proper size the tone will be reinforced. Such a resonator will selectively vibrate to one component in a complex wave. Helmholtz utilized this principle for analyzing out partials from a Klang by constructing small hollow brass air chambers with two apertures, one fitting into the ear, the other directed toward the sound. The chambers could be adjusted to any pitch and reinforced tones of that pitch only. Thus each partial could be analyzed out of a Klang tone.

There is also the possibility of producing *forced* resonance, where the interval between the generating tone and the resonator is less than a semitone, although the duration and intensity will be less.

Finally, it is possible to secure partial resonance; (1) Where the generating tone has high frequency and the lower harmonic resonator responds with a high partial which corresponds to the generator in pitch; (2) where the generating tone has low frequency, and one of its partials stimulates a higher harmonic resonator to respond.

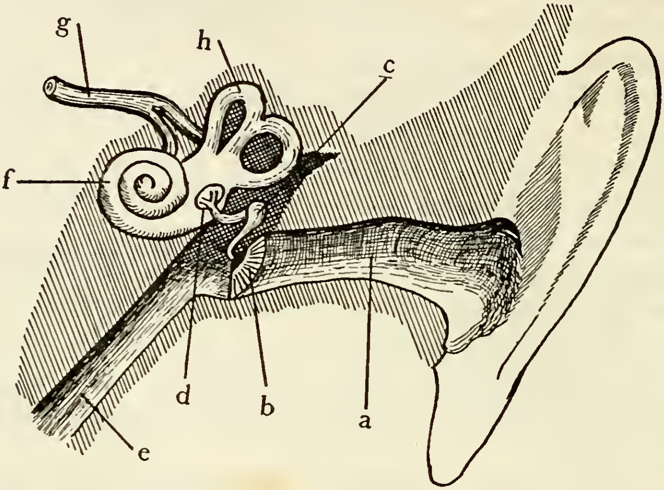


Fig. 18. The auditory mechanism

a. external meatus; *b.* tympanic membrane; *c.* ossicles; *d.* oval window; *e.* eustachean tube; *f.* cochlea; *g.* auditory nerve; *h.* semicircular canals.

ANATOMY OF THE EAR

Gross Anatomy. — Three parts are distinguishable. (a) The external part, consisting of the *auricle* for focalizing and reinforcing sounds, and the *external meatus,* or canal conducting to the middle ear. (b) The middle ear, an air filled cavity (with small passage into the mouth to equalize pressure) separated from the meatus by the *tympanic membrane,* a flat cone-shaped membrane consisting of radial and concentric fibers, with apex inward. A chain of three jointed ossicles (malleus, incus, and stapes) is stretched across the cavity from the tympanic membrane to the membrane which covers a *small oval window* in the inner wall connecting with the internal ear. Directly below the oval window lies the round window. The ossicles are held in place by two muscles, the stapedius and the tensor tympani. Vibrations of the tympanum cause lever movements of the malleus and incus about a fulcrum, thus somewhat reducing the amplitude of the vibrations transmitted from tympanum to oval window. (c) The internal ear, a bony cavity containing a membranous cavity within it. Directly behind the oval window is the *vestibule* which communicates with the semicircular canals and organs of equilibrium on one side, and, on the other, the *cochlea,* the organ of hearing. The latter is a winding tubular cavity which makes two and a half revolutions around a central bone trunk, the *modiolus.* The lamina

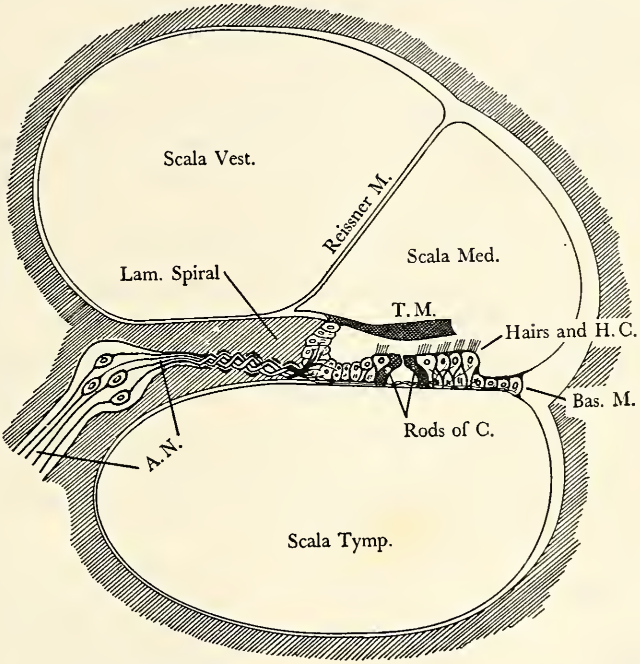


FIG. 19. The cochlear canal

spiralis, a bony ledge, projects into the tubular cavity, and to its tip is attached the membranous tube, or cochlear canal filled with endolymph. The sides of this tube are formed by the Reissner membrane and the basilar membrane. Above the Reissner membrane is the scala vestibuli and below is the scala tympani, both long canals filled with perilymph. They communicate with one another at the apex through a small opening, the helicotrema. The scala tympani terminates at the round window, which lies just below the oval window.

Minute Anatomy. — On the basilar membrane lies the *organ of Corti.* This contains an arch formed by a double row of *rods,* making a tunnel running the length of the membrane. About the rods are grouped supporting cells, above which lie the hair cells on either side of the arch. Over the whole organ is stretched the reticular membrane, from the lamina spiralis to the basilar membrane, with openings for the hairs to project into the cochlear canal. Projecting freely into the cochlear canal from the lamina spiralis and overhanging the organ of Corti, is the tectorial membrane. At the end where the basilar membrane joins the bony wall is the spiral ligament which may possibly control the tension on the membrane. The following measurements are important for auditory theory. Estimates differ:

Organs	*Number*	*Variation in Length and Thickness*
Basilar fibres	24,000	Increases about 3 times from base to apex
Rods of Corti	From 3,000 to 9,000	Unknown
Hairs	225,000 About 20 per hair cell	Unknown
Tectorial membrane fibres	Unknown	Variation in width 3:1 Variation in thickness 5:1

Neural Connections. — The cochlear branch of the auditory nerve has dendritic endings near the hair cells of the cochlea; it conducts to ganglia in the modiolus, and thence to the terminus of the first axone in the medulla. The second neurone crosses to the lower quadrigemina, medial geniculate body and inferior brachium. The third neurone extends via internal capsule to the projection center in the superior convolution of the temporal lobe.

The Essential Structures. — The path of sound conduction, from the vibrating physical body to the auditory nerve termini, is as follows: — (a) Molecular vibration of air to tympanic membrane; (b) molar vibration of membrane; (c) molar oscillation of chain of bones; (d) molar vibration of oval window membrane; (e) either molar displacement or molecular vibration of liquids (lymphs). However, not all these steps are essential to the production of sound. If the chain of bones is absent, the air can conduct vibrations across the middle ear to the oval window. If both tympanum and chain of bones are lacking, air vibrations can be received through the outer ear and mouth. The cranium can receive and transmit vibrations to the cochlea, by bone conduction. Finally, pitch and intensity differences can be received cutaneously. Gault has used this method with deaf subjects.

THE EXPERIMENTAL FACTS OF HEARING

I. PITCH, LOUDNESS, AND TIMBRE

AUDITORY experiences fall into two large classes, *tones* and *noises*. The former, caused by periodic vibrations, have pitch, and can therefore be arranged in a one dimensional pitch series. The latter (caused by a-periodic vibrations) lack constant pitch, are rough and broken. (a) *Klangs.* Most tones produced by a vibrating body are complex, consisting of the fundamental and the various audible overtones. These are heard, though not necessarily recognized by the untrained ear. Such complex tones or Klang tones differ in the following directions — pitch, intensity, timbre, and possibly volume.

Pitch. — There are 11,000 different tonal qualities, forming the pitch series. Not all rates of vibrations produce sound; only those lying between the upper and lower stimulus thresholds. The lower threshold is about 20 d.v./sec. though some hear frequencies as low as 16 d.v./sec. or lower. Below this, they are felt cutaneously as puffs of air. This can be demonstrated with tuning forks of 12 d.v./sec. rate. The upper threshold is around 20,000 d.v./sec. This can be demonstrated by the use of a Galton whistle, an instrument calibrated for very high tones and operated by air pressure from a hand bulb. Between these extremes, individuals differ greatly in their ability to differentiate slight differences in pitch. The amount of difference in the vibration frequency of two tones necessary to give a J.N.D. in pitch is called the pitch differential threshold. It varies for different absolute levels. Discrimination is poor toward the upper and lower limits and good in the central range of frequencies, where differences of $\frac{1}{2}$ to $\frac{1}{4}$ vibration per second can be detected. Hence Weber's law can only be said to apply to a very limited range of the pitch series. At low or very high intensities, pitch discrimination is less acute than at medium intensities. The pitch discrimination of some persons is poor in certain ranges. These are called tonal gaps. There is some evidence to the effect that such gaps are correlated with segmental structural or functional defects in the cochlear membrane. When the range is reduced at both ends so that only a few octaves remain, the region left intact is called a tonal island.

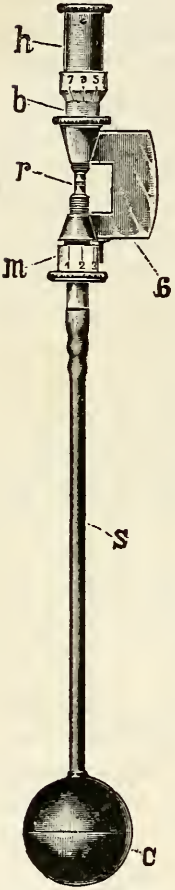


Fig. 20.
Galton whistle
Courtesy of C. H. Stoelting Co.

The normal pitch range is punctuated by points of reference, the *octaves*, whose vibration frequencies are related to one another in geometric progression, each one having twice the frequency of the one below. Each octave is further subdivided into a scale of intervals within it, eight in number, c,d,e,f,g,a,b,c. In the major diatonic scale (letting the tonic or first note equal unity) these intervals bear the following ratios to one another: — 1, 9/8, 5/4, 4/3, 3/2, 5/3, 15/8, 2.

The consecutive intervals from c to c_2 are called a second, a major third, a fourth, a fifth, a major sixth, a major seventh, and an octave, respectively. To get the relative sizes of the successive intervals, it is necessary to divide each ratio by the preceding, giving: — 9/8, 10/9, 16/15, 9/8, 10/9, 9/8, 16/15. It will be seen that there are only three different sizes of interval between consecutive notes, i.e., 9/8, which is a major tone, 10/9 which is a minor tone, and 16/15 which is a major semitone.

Loudness or Intensity. — In addition to the pitch thresholds there are two intensity thresholds: the absolute lower threshold of audibility, and the differential threshold. When the intensity is increased beyond a certain amount there is a sensation of acute pain which is probably tactile in origin. The absolute threshold for audition can be stated in terms of the root mean square of the change in pressure on the tympanic membrane — dynes per square centimeter. The average sensitivity for normal ears varies from .15 dynes/cm.^{2} at 60 d.v. to .001 dynes/cm.^{2} at 1000 d.v., remaining constant to 4000 d.v. and thereafter decreasing rapidly. The intensity difference limen varies with the pitch of the tone. Weber's law is said to hold for each separate tone for intensities exceeding 106 times the minimal audible intensity, but varies from tone to tone.

Timbre. — This is a function of the number, and loudness and pitch of the overtones or partials which enter into the Klang tone. Helmholtz demonstrated this by constructing the timbre of various instruments and the human voice synthetically out of simple tones merely by varying the pattern of partials. The complex wave produced by the human voice can best be demonstrated by an instrument called the 'phonoprojectoscope,' shown in Figure 21. The number of partials varies from zero in the case of the tuning fork, up to 15, or more. Certain strings of the violin have partials which are louder than the fundamental. Since partials bear the ratios 1:2, 1:3, 1:4, etc. to the fundamental, they are, for the fundamental note, C, in order, C^1 G^1 C^2 E^2 G^2 C^3 D^3 E^3 G^3, etc.

Volume. — Sounds differ subjectively in their volume.

Those of high pitch are small and attenuated; those of low pitch are large and voluminous; or, in general, the volume is inversely proportional to the frequency. The question as to whether volume is one of the elementary attributes of sound is a disputed one. Rich gives evidence that the threshold of pitch discrimination differs from that for volume. The assumption is therefore that the two must be independent variables. Halverson found that volume varies directly with loudness, but that, again, the limens for the two follow a different law and hence they must be independent variables. (Boring suggests that, since the energy of a tone is proportional to the square of the product of its amplitude and frequency, the amplitude of low tones of equal energy would be greater than that of high tones, and that therefore the apparent variation of volume with pitch is really a variation with amplitude.) These findings support the theory that volume is an elementary attribute, analogous to extensity in vision. But other evidence, to the effect that the apparent " volume " of sounds varies with their location and the degree of definiteness of the source of the sound, makes it appear that volume is a perceptual complex.

II. THE ANALYTICAL POWER OF THE EAR

Since the air wave which arouses auditory response may be extremely complex, containing many component tones, the question arises as to how the auditory mechanism analyses out the component parts so that the subject hears them individually. All theories of audition assume some sort of analytical mechanism but differ as to the nature of the process, its location, and the specific structure involved. The fact of tonal analysis itself is undeniable. As in vision, there is the necessity of explaining, on the one hand, the *independence* of pitch quales, such that (1) each pitch can be experienced uniquely, (2) two or more pitch quales can be simultaneously experienced independently of each other, and (3) as in color blindness, the different pitches can appear functionally independent in disease. And, on the other hand, it is necessary to explain the mutual *interdependence* of pitch quales in such phenomena as beating, combination tones, tonal fusion, consonance, and dissonance, and binaural relationships.

III. BEATS

The alternate reinforcement and weakening effect resulting from simultaneously sounding two tonal stimuli of neighboring frequencies has been described *physically,* as interference of air waves. But not all beating can be accounted for so easily. Beating may occur between fundamentals, partials, or combination tones. The rate is always determined by the formula h—l. But if the generating tones are very close, not more than 6 d.v./sec. apart, a single beating tone is heard. This is known as the *intertone.* If they are as much as a semitone apart, they maintain their separate pitches, and a third beating tone is heard between the two generators, nearer the lower one. If more than a semitone apart, either generator which is attended to seems to carry the beats.

IV. COMBINATION TONES

When two pure tones are sounded together strongly, certain additional tones are produced, much weaker than the primaries, called *combination tones.* (They are also called Tartini's tones, from the name of an Italian violinist, though first discovered by Sorge, in 1745.) Two distinct types have been identified, the *first summation tone,* and the *first difference tone.* Their formulae are as follows:

First Summation tone: Sum of primaries, or $L+U$
First Difference tone: Difference of primaries, or $U-L$

The formula for the difference tone is identical with that for beats. For this reason, it is sometimes called a beat tone on the theory that it results from the fusion of the beats into an independent tone where the primaries are far enough apart so that the beats occur too rapidly to be separately apprehended. But both beats and difference tone can be heard simultaneously.

In addition to the combination tones of the first order, there are weaker ones of the second order, whose formulae are:

Second Difference tone: Difference between upper and twice lower primary, or $2L - U$
Second Summation tone: Sum of upper and twice lower primary, or $2L + U$.

That these are genuine tones rather than partials is shown by the fact that difference tones can be lower than the primaries, and they can be generated by pure tones, as from tuning forks.

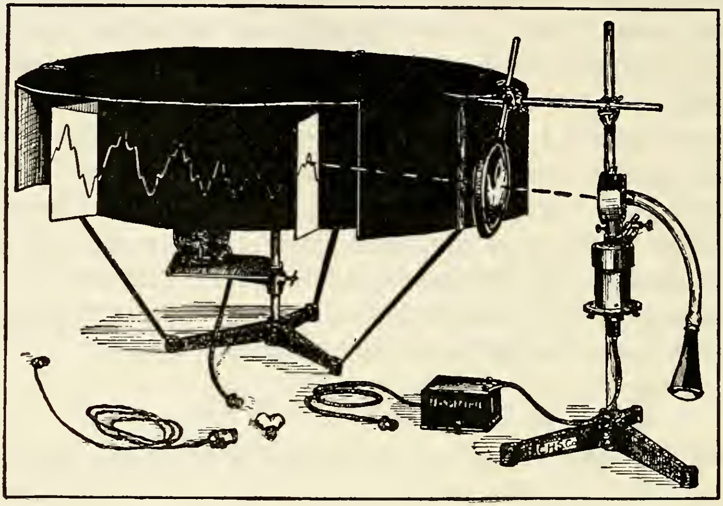


FIG. 21. Phonoprojectoscope

Designed by Metfessel. Courtesy of C. H. Stoelting Co.

Are combination tones physical, or peripheral (i.e., due to structure of ear), or purely subjective (i.e., cortical) in origin? That some are physical is shown by the fact that they can be resonated. Such are produced by generators from a common wind chest. That the rest are physiological is demonstrated by the fact that they are only produced when both generating tones are conducted to the same ear. Since persons who lack the middle ear mechanism can hear them, they are probably cochlear in origin.

Difference tones can be obtained best from forks of high pitch, while summation tones require low pitched generators.

V. FUSION

When two or more simple tones are simultaneously experienced, they lose their uniqueness, and fuse to a greater or less degree, depending, among other things, on (1) their pitch relation, (2) their timbre relations, (3) their origin, (4) their intensity ratio. The fundamental and partials from a common generator (i.e., harmonics) give the greatest fusion. Tones of the same pitch from different generators fuse best when the generating instruments have similar timbre. When the two primary tones are different in pitch the degree of fusion depends on the interval. Octaves fuse better than fifths, fifths better than sevenths, etc. Beating prevents fusion.

VI. CONSONANCE AND DISSONANCE

These terms are used with differing meanings. They are related to, but not identical with, fusion, harmony, musicality, affective value, etc. It is advisable not to confuse affective categories with sensory quale distinctions. Hence the terms consonance and dissonance should be given sensory meaning, such as presence or absence of beats, or fusion, or degree of familiarity with the interval.

Since the theories of fusion and consonance are independent of general auditory theory, they may be summarized here. Some theories of fusion are

(1) *Identity of partials.* — The degree of fusion is supposed to be a function of the number of partials of equal pitch generated by the two fundamentals. This would explain why the intervals whose ratios are small, as 4/3, 3/2, etc., fuse best. It would also account for the better fusion of instruments of like timbre. But pure primaries fuse. Ebbinghaus has assumed that the basilar fibers are capable of partial vibration and hence the same resonator would be involved in both tones, where they fell within the harmonic series.

(2) *Krueger's theory of identity of difference tones.* — This depends on a false derivation of the difference tones.

(3) *Racial habit.* — Since a fundamental and its overtones are most often heard together as a simple experience, the

harmonic series would be firmly associated and these intervals would naturally fuse in experience. This accounts for the dependence of fusion on the harmonic ratios, the fusion of pure primaries, and the fusion of Klangs of like timbre.

The chief theories of consonance and dissonance are:

(1) *The beat theory of Helmholtz.* — Beats cause dissonance; absence of beats consonance. If the primaries are too far apart to beat, as in the seventh, then it is beating of partials.

(2) *The fusion theory of Stumpf.* — Intervals which fuse are consonant. Others are dissonant.

(3) *The unconscious counting theory of Euler.* — The ease of counting is proportional to the simplicity of the ratio. Hence the simple ratios are easy or consonant.

(4) *Neural rhythm theory of Lipps.* — The simultaneous performance of two rhythmic reactions is easier when their frequency ratio is simple.

(5) *Theory of identity of difference tones.*

(6) *Genetic theory of Moore.* — History shows that the intervals once thought dissonant, as the third, are now thought consonant. Hence ideas of consonance have developed, and people react in conformity to their cultural period. Experiment shows that subjects can be made to consider consonant those intervals which were originally pronounced dissonant, by frequent repetition of the interval. Peterson has defended a functional view of consonance, similar to Moore's.

That fusion and consonance are not identical is shown by the relatively high fusion value and low consonance value of the octave.

VII. BINAURAL RELATIONSHIPS

The significance of binaural results for auditory theory depends on the assumption that it is possible to stimulate the two ears independently, so that neither peripheral mechanism is affected by both stimulations. Of course the possibility of bone conduction, or eustachian tube conduction, must be considered.

To begin with, there is a pitch difference between the two ears, averaging 5 or 6 vibrations in the middle range, which results in hearing a tone higher in the right ear. But when the ears are simultaneously stimulated only one tone is heard, which shows no beats, even though the two pitches are within the beating range. An exception to this is the rare phenomenon of double hearing, in which each ear hears a sound and the two do not fuse.

When two tones of neighboring frequencies stimulate the two ears independently, there occur binaural beats. Either these must be explained on a central theory of beats, or else cranial bone conduction, etc., must be invoked.

VIII. SPECIAL EVIDENCE

THERE are certain particular facts which have important theoretical bearing on the theories of audition.

(1) *Disorders of hearing*

(a) The fact of tonal gaps and tonal islands has already been described. Lacunae in the upper ranges are supposedly correlated with lesions in the lower cochlea and vice versa. Some evidence has also been found for gaps in the intensity series.

(b) *Boiler maker's disease* is a loss of hearing for sounds in the upper pitch range. It is thought to be caused by the constant intense stimulation received in this range, and is correlated with limited lesions in the lower part of the cochlear canal near the oval window.

(2) *Experiments on animals*

(a) *Yoshii* subjected guinea pigs to continuous stimulation from musical tones of a given pitch for periods up to 60 days. The highest pitch used was 4138 D.V./sec; the lowest 193 D.V./sec. The animals were then killed and the cochlea examined for lesions. He found deteriorations over from a fourth to a half of the cochlea. They occurred most frequently toward the base.

(b) Contradictory experiments of Baginsky and Stepanoff are reported in Schaefer's Physiology. The former got deafness to high tones from lesions near the base. The latter failed to get deafness to low tones in guinea pigs from destruction of the apex.

In general, the methods of determining tonal sensitivity in animals have not been very reliable.

(3) *Wever and Bray's experiment*

By applying an electrode to the auditory nerve of a cat, in the region of the medulla, and conducting the action current to a telephone receiver, they obtained for sound stimuli of frequencies from 125 to 4500 D.V./sec., tones in the telephone receiver of the same pitch as the stimulus. This shows that the auditory nerve carries the frequencies of the air wave in terms of frequencies of neural impulse. This is contrary to the findings for other sensory nerves, by Adrian, to the effect that intensity of stimulation is correlated with frequency of nerve response. Its theoretical significance is ambiguous, as will be shown later.

The Theories of Audition

General theories of hearing may be classified in three groups, in accordance with the mechanism in terms of which they explain the analytical process in hearing. Theories are either *Central,* or *Peripheral;* and the peripheral theories are either *Resonator* or *Non-Resonator.*

Central Theories

The typical central theory is the Telephone theory of Rutherford. It assumes that the entire peripheral mechanism vibrates in a unitary manner, in harmony with the complex vibration of the air particles, like the disc of a telephone. The nerve endings are therefore all involved in every stimulation, rather than being selectively stimulated by different frequencies or intensities. The burden of analysis depends therefore on differentiations in the nature of the nerve impulse (carried indifferently by all fibers) to which the auditory cortex responds selectively, in terms of some sort of anatomical differentiation of cortical cells or regions. Some peripheral theories take advantage of the telephone principle, as Meyer's displacement theory, without, however, throwing the burden entirely on the cortex.

The objections to central theories are: (1) That no evidence exists for a real specificity of functioning in the auditory cortex such as is demonstrable in pattern vision in the visual cortex; (2) That no auditory cortical lesions have been discovered, correlative with the tonal gaps and tonal islands in persons of defective hearing; (3) On the other hand, limited lesions in particular regions of the cochlea have been found to accompany such tonal gaps, pointing toward peripheral specificity of functioning.

Peripheral Non-Resonator Theories

These have been called frequency theories since most of them assume that pitch is a function of the frequency of the stimulations received by the nerve endings rather than depending on the part of the basilar membrane stimulated. Meyer's theory is given as an example because it is carefully worked out on the basis of the pertinent psychological facts.

I. *Max Meyer's Displacement Theory.*—Consideration of certain physical and physiological principles led Meyer to deny the possibility of a resonator theory, and to devise an entirely different one. These are: (1) The fact that the liquid of the cochlear membranous canal would be noncompressible, and hence would be displaced as a whole, by the impacts of the stapes through the oval membrane; (2) the fact that the average sound wave would be at least a meter in length, and that it is therefore preposterous to suppose that such waves could travel in a canal which is only a small fraction of a meter in length; (3) the fact that living tissues like the basilar membrane are incapable of maintaining such a constant tension as would be necessary to act as resonators.

Meyer therefore assumed that the basilar membrane acts as a whole, being depressed with each impact of the stapes; that such displacement will have a longitudinal extent proportional to the strength of the impact, and that hence the *loudness* of the sound will be determined by the extent of the depression, and the resulting number of nerve endings stimulated. Since all the nerve fibers would respond indifferently, *pitch* would be explained as due to the *frequency* with which the basilar membrane is depressed, and hence the frequency of nerve excitation. In the case of complex waves, he has shown how the different component frequencies will affect different portions of the membrane in such a way that they will be separately transmitted to the brain. He has given a plausible basis also for the production of extra tones under certain circumstances for which there is no corresponding component in the stimulus, thus accounting for combination tones of subjective origin.

While Meyer has thus provided for peripheral analysis of complex tones, and peripheral intensity analysis, he has still the necessity of explaining pitch discrimination centrally, since all the nerve fibers merely respond with a certain frequency of impulses. The rate of response for very high tones would exceed the known capacity of peripheral nerve fibers to respond; i.e., over 20,000 impulses per second, assuming a refractory period of from 0.43 to 4.5 thousands of a second. But with many fibers acting at once, they might share the burden between them. His theory is therefore open to the same objections offered against a central theory. Localized cochlear lesions, as in boiler maker's disease, and in Yoshii's guinea pig experiment, might, however, be explained as intensity effects; since weak intensities would be confined to the base of the cochlea, and strong intensities would involve the apex as well. There would still remain unanswered the fact of tonal lacunae, previously mentioned. Boring quotes evidence that tonal lacunae can be overcome by increasing the intensity of tones in the affected range.

II. *Wrightson's Theory.*—This is similar to Meyer's theory but brings out the additional point that there are four separate stimulations to the auditory mechanism received from the successive phases of a single sine wave. This explains mathematically the production of combination tones, but unfortunately accounts for some which do not exist.

III. *Ewald's Sound Pattern Theory.*—This is based on the theory that each complex sound wave projects a characteristic pattern of vibration on the basilar membrane, in the form of fixed waves. To demonstrate this, he constructed an artificial membrane of thin rubber stretched across a hole in an aluminum plate, and then held the end of a vibrating tuning fork to the membrane. The result was that a series of nodes or dark waves could be observed with a microscope, whose number varied with the pitch of the fork in multiples up to six octaves, and whose distance apart was inversely proportional to frequency. Analysis of the pattern showed all the components of complex *Klangs* present. Intense vibrations produced sharper waves.

If the basilar membrane is conceived to vibrate similarly then a different pattern of hair cells and hence of nerve termini lying opposite would be stimulated for each different tonal stimulus. These patterns would be appreciated as qualitative differences by the auditory cortex and every conceivable combination of complex tones could be analyzed out, provided the basilar membrane could carry such complex patterns, which is questionable.

Peripheral Resonator Theories

It is a common assumption of such theories that there is some structure in the cochlea with enough distinct parts varying in length, thickness, or tautness (like piano strings) to be capable of acting as selective resonators, vibrating analytically to the various components in a complex wave, and stimulating the underlying hair cells. Helmholtz first chose the rods of Corti, but their number is too small, their range of sizes inadequate, and they are absent in non-mammalian animals like birds, which have pitch discrimination. Ayers chose the hair cells but though their number is sufficient it is not known that their size variation is adequate. Shambaugh and Hardesty chose the tectorial membrane, which is fibrous, and increases fifteen times in size from base to apex of cochlea. It is difficult to conceive how the requisite tautness could be achieved and how fibers which form a continuous membrane, as the tectorial or basilar fibers, could vibrate independently.

I. *The Helmholtz Theory.*—Helmholtz and Hensen finally settled on the basilar membrane, whose fibers are 24,000 in number, and vary in length being short at base and long at apex. But their size range is only enough to account for a range of two or three octaves. Variations in tautness are supposed to be produced by the action of the spiral ligament, or the stria vascularis, or in some other manner. The chief objection is that the membrane is heavily loaded by the organ of Corti making free vibration doubtful. A physical model was constructed by McKendrick, which is claimed to resonate in the manner postulated by Helmholtz.

Assuming that the basilar fibers are capable of selectively vibrating to 11,000 different pitches, then the problem of analysis of *Klangs* and *Klang* combinations is solved, and also the capacity for independent experiencing of tones. It is due to physical isolation of parts. On the other hand, all phenomena demonstrating interaction of parts, as beats, combination tones, and fusion, require explanation.

Beats.—Subjective beating is explained as due to forced resonance of the basilar fibers. Any two simultaneous tones less than a semitone apart would stimulate common resonators. The beating would then be the result of the effort of these common resonators to respond simultaneously.

When the two generators are more than a semitone apart the beating is attributed to interference of their overtones. Yet pure tones of more than a semitone separation will beat. Therefore it is assumed that the combination tones generated by the primaries cause the beating. This is questionable since the beats are too loud; and it is the primaries that are experienced as carrying the beats. Ebbinghaus suggested that in this case the basilar fibers are responding with partial resonance in the manner already described for physical resonators. Binaural beating would require explanation in terms of bone conduction, so that the same cochlea received both vibrations.

Combination Tones.—Some of these are objective. When they are subjective in origin they are explained by Helmholtz as due to interference, causing asymmetrical vibrations of the ossicles or drum membranes, a phenomenon which has been demonstrated on a physical model. But the hearing of combination tones has been reported by Peterson in the case of persons who have lost the structures of the middle ear. However, they might still be accounted for in terms of the action of the oval window membrane.

Loudness.—This was originally attributed to the strength with which the underlying nerve fibers are stimulated due to the amplitude of resonant vibration of the basilar strands. But the "all or nothing" law of nerve action precludes the possibility of a single nerve fiber responding with more than one intensity. It is therefore necessary either to assume, as Hartridge has suggested, that *many fibers* lying within a limited pitch range are stimulated by loud sounds, giving a summation effect at the center, or to assume, with Forbes, that increased magnitude of vibration of the basilar strands causes an increase in the *frequency* with which the underlying nerve fibres react. This latter hypothesis agrees with Adrian's findings for other sensory nerves.

Comparison of the Theories. — The evidence for and against the three main types of theory seems about equally divided. As they were originally stated, none of the theories was tenable. But with the appropriate corrections, all are possible. Workable physical models have been built on the plan of each of the chief hypotheses. Hartridge has demonstrated that the ear shows the existence of certain properties which are characteristic of resonators, i.e., sharpness of resonance, persistence of vibration, etc. On the other hand, there is evidence pointing to pitch discrimination with no cochlea and presumably no other system capable of differential resonance. Hearing has been reported in persons with both cochleas absent. Von Frisch reports studies of pitch discrimination in fish in which only the single otolith organ was present, to act as resonator. This would favor a simple telephone theory. Wever and Bray have suggested a volley theory to avoid the refractory phase limitation to a frequency neural hypothesis of pitch discrimination.

Probably the most fruitful directions for future experimentation lie in (1) a more adequate histology of the inner ear, (2) a further study of the behavior of the auditory nerve in mammals, and (3) studies of the correlation of functional defects with localized lesions either occurring naturally in human subjects or experimentally produced in animals.

REFERENCES

Adrian, E. D., & Zotterman, Y. The impulses produced by sensory nerve endings, Part 2. *J. Physiol.*, 1926, 61, 151–171; Part 3, 465–483.

Ayers, H. Vertebrate cephalogenesis. II. A contribution to the morphology of the vertebrate ear, with a consideration of its functions. *J. Morph.*, 1892, 6, 1–360.

Baginsky, B. Die Function der Gehörschencke. *Arch. f. Anat. u. Psysiol.*, 1883, 94, 65–85.

Boring, E. G. Auditory theory with special reference to intensity, volume, and localization. *Amer. J. Psychol.*, 1926, 37, 157–88.

Ebbinghaus, H. Grundzüge der Psychologie. Leipzig. Veit & Co., 1925.

Ewald, J. R. Zur Physiologie des Labyrinths. VI. Eine neue Hortheorie. Pflüg. *Arch. f. d. ges. Physiol.*, 1899, 76, 147–188.

Gundlach, S. Tonal attributes and frequency theories of hearing. *J. Exper. Psychol.* 1929, 12, 187–196.

Halverson, H. M. Tonal volume as a function of intensity. *Amer. J. Psychol.*, 1924, 35, 360–367.

Hardesty, I. On the nature of the tectorial membrane and the probable role in the anatomy of hearing. *Amer. J. Anat.*, 1908, 8, 104–179.

Hartridge, H. Hearing II, Chap. 7 in Murchison's *Foundations of experimental psychology,* Worcester: Clark Univ. Press, 1929.

Helmholtz, H. On the sensations of tone. (Transl. by A. Ellis) 3rd ed. London: Longmans, 1895.

Helmholtz, H. Sensations of tone. (Transl. by A. Ellis) 4th ed. 1877, p. 194.

Krueger, F. Consonance and dissonance. *J. Phil., Psychol., and Scientific Method,* 1913, 10, 158–160.

Krueger, F. Die Theorie der Konsonanz. *Psychol. Studien,* 1906, 1, 305–387; 1907, 2, 205–355; 1909, 4, 201–282; 1910, 5, 279–411.

Lipps, T. Psychologische Studien von Theodor Lipps. Leipzig, 1905. Durr'-sche Buchhandlung.

McKendrick, J. G. See Shaefer's textbook of physiology. P. 1182.

Meyer, M. An introduction to the mechanics of the inner ear. Columbia: Univ. of Missouri Studies, 1907.

Moore, H. T. The genetic aspect of consonance and dissonance. *Psychol. Rev. Monog. Suppl.,* 1914, 17, No. 73, p. 80.

Peterson, J. A functional view of consonance. *Psychol. Rev.,* 32, 1925, 17–33.

Peterson, J. Combination tones and other related auditory phenomena. *Psychol. Monog.,* 1908, 9, no. 39. Pp. xiii–136.

Rich, G. J. A preliminary study of tonal volume. *J. Exper. Psychol.,* 1916, 1, 13–22.

Rutherford, W. A new theory of hearing. *J. Anat. and Physiol.,* 1887, 21, 166–168.

Schaeffer, E. A. Textbook of physiology. New York: Macmillan. 1900.

Shambaugh & Knudson, V. O. *Amer. Otol. Soc.,* 1923.

Stepanoff, E. M. Experimenteller Beitrag zur Frage über die Function der Schniecke. *Monatsschr. f. Ohrenhk.,* 1888, 22, 85.

Stumpf, C. Tonpsychologie. Leipzig: S. Hirzel, 1883–90, pp. 127 ff.

Wever and Bray. Action currents in the auditory nerve in response to acoustical stimulation. *Proc. Nat. Acad. Sci.,* 1930, 16, 344–349.

Wever and Bray. Present possibilities for auditory theory. *Psychol. Rev.,* 1930, 37, 365–380.

Yoshii, U. *Zeits. f. Ohrenheil-Kunde,* 1909, 58, 201–250. For figure see Wilkinson, G., & Gray, A. A., Mechanism of the cochlea, 1924, pp. 200.

CHAPTER IV

CUTANEOUS SENSITIVITY

THE cutaneous group of sensory processes is not homogeneous, but probably consists of four distinct types of sense organ correlated with four qualitatively distinct sorts of experience. Their common characteristic is a rather wide distribution of all the four types over the surface of the body. The four modes of sensation are contact, warmth, cold, and pain. A fifth sensation, deep pressure, is not properly included, since it is probably mediated by structures lying below the skin rather than in it.

The Adequate Stimuli

Contact. — It is agreed that the adequate stimulus to contact is a deformation of the skin, due to the action of a mechanical force upon it. When a large area of skin is acted upon uniformly, as when the finger is immersed in water, the contact is felt only at the point where the finger emerges from the liquid. Hence mere pressure is not an adequate stimulus. There must be deformation. Thus either a push or pull on one of the hairs will arouse a contact sensation. Contact may be aroused by either punctate or areal stimulation.

Pain. — There is no specific kind of stimulus to pain. Rather there is an upper threshold of intensity for each cutaneous stimulus beyond which it will elicit pain. This is also true of vision or hearing though it is not certain that the pain elicited in these fields is not cutaneous pain. Not all regions of the skin are subject to pain stimulation, showing that the end-organ, if not the stimulus, is specific.

Warmth and Cold. — It was once supposed that these were both elicited from differential stimulation of the same sense organ. Now it is held that warmth and cold have distinct sense organs. But, on the stimulus side, it is the same form of energy which arouses both, i.e., physical heat of different degrees. Since the body itself manufactures heat energy it is warmer than most objects with which it comes in contact and hence radiates heat to the surrounding environment. The *physiological zero* would be that point at which heat production in a given area is exactly equal to its rate of transmission. Under these conditions no temperature sensation would occur. The capacity of the skin to adapt rapidly to constant external temperatures causes the physiological zero to change from time to time, and for different parts of the body simultaneously. The range of temperature within which adaptation may occur is called the *adaptation range.* Thus an adequate stimulus to temperature sense occurs when the skin temperature remains above or below the adaptation range or when there is a rapid change within the range. Hence neither Vierodt's theory which attributes heat and cold to the direction of transmission of heat, to or from the body, nor Weber's theory which explains them by the rise or fall of the temperature of the end-organ, is adequate. Hering has correctly stated the adequate stimulus as the difference between the temperature of the end-organ and that of the physiological zero of the given region at the given time.

INADEQUATE STIMULI

Electric current, applied to the skin, will elicit any of the four types of cutaneous sensitivity. Cold spots react paradoxically to warm stimuli, to mechanical tapping, and to menthol; warm spots to tapping and certain chemicals; contact spots to radiant heat and to sound waves; and pain has already been described as nonspecific.

THE ANATOMICAL FACTS

In spite of considerable histological work, very little is definitely established about the cutaneous end-organs. Many types of terminal organ have been isolated, and their functions guessed at. But further research has disclosed that the functions can be performed in the absence of these terminal organs. The assumption on which investigators have previously worked is that there is a spatial differentiation of nerve termini corresponding to the functional differentiation of the cutaneous qualia in experience. Nafe has recently suggested that the apparent qualitative distinctions are at bottom quantitative and have their origin, not in discrete types of terminal organ, but rather in a continuum of intensities of stimulation of the same nerves. This fits very nicely the relation of pain to the other qualia but fails to explain the jump from contact to temperature; for no amount of stimulation of certain spots which respond to contact will elicit temperature responses.

The main types of cutaneous nerve termini will be described and the correlations with specific functions, in so far as they have been worked out by Von Frey and others.

The skin consists of the epidermis with its three strata and underneath it the dermis corium with its two layers, the papillary and the reticular.

The End-organs

1. *Free nerve endings* consist of arborized termini of nerves, having merely non-medullated tips or endplates, with no specialized organ. These endings are found in the epidermis where they make contact with every epithelial cell.

2. *The hair nerves,* entering the roots of the hairs and terminating in a plexus, about the hair follicles. Another type of organ, the Merkel's Tastsellen, which are modified epithelial cells, are found in the lower epidermis and around the hair follicles.

3. *The Meissner corpuscles* are found abundantly under the hairless surfaces, at the tips of the papillae of the dermis. They consist of a capsule containing a group of oval cells penetrated by non-medullated nerve fibrils.

4. *The Krause Bulbs* are small rounded structures filled with granular matter penetrated by the wound end of the non-medullated nerve fiber. A similar but larger type of organ, the Pacinian corpuscle, is located only in the subcutaneous tissue.

5. *The Ruffini cylinders* are long cylindrical bodies with a connective tissue sac, found between the skin and the subcutaneous tissue. One nerve may furnish five of them.

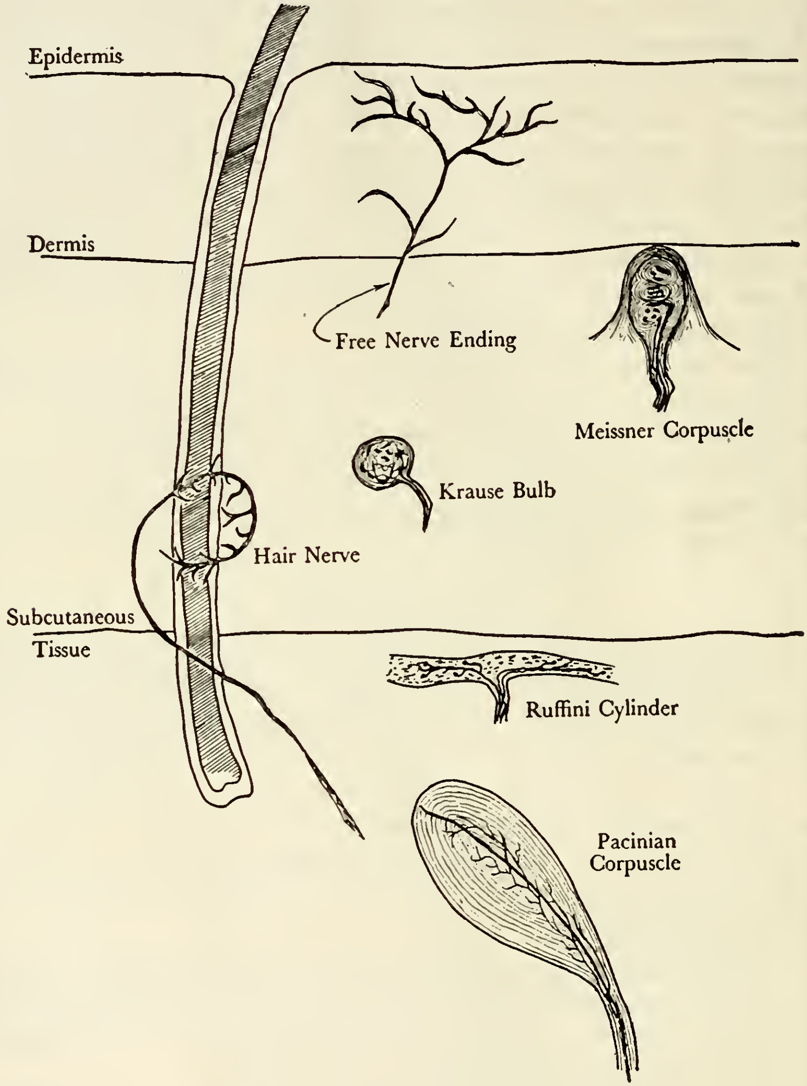


FIG. 22. The cutaneous end-organs

Their Supposed Functions

Pain has been correlated with the free nerve endings since (1) both are distributed most widely; (2) pain is localized superficially, and the skin is more sensitive than underlying regions; (3) regions like the cornea, showing only pain and cold sensitivity, are rich in free nerve endings; (4) many visceral regions are only sensitive to pain, and contain free nerve endings; and (5) the limen for pain is high, a thing which would be expected of non-specialized end plates.

Contact is attributed to the hair nerves and Tastsellen in the hairy regions, and to the Meissner corpuscles in the hairless regions. The reason is that the skin is most sensitive to touch immediately over the hair roots. The contact sensitivity between hairs is attributed to the Tastsellen, which are present on all areas of the skin in the epithelium. On hairless portions, the Meissner corpuscles, which occur nowhere else, have a frequency distribution about equal to that of the touch sensitive spots. Thus the fingertip contains 50 per sq. mm., whereas the sole of the foot contains only 3 per sq. mm.

Cold is correlated with the Krause bulbs, because regions like the cornea and glans penis, which are most sensitive to cold have a rich supply of these structures. But they are absent from other regions which are sensitive to cold, and recent experiments by Dallenbach and others in which cold spots were marked, and the underlying skin examined histologically, show none of these organs. Dallenbach found no end organs of any sort opposite certain of these spots. His work corroborates the pioneer research of Donaldson, who performed the first crucial histological work in 1885.

Warm has been attributed to the Ruffini cylinders, principally because the long reaction time to warmth, and the diffuseness of the sensation fit in with the deep location of these structures. But, as with cold spots, Dallenbach and others have found specific organs absent from areas which give warm sensations.

The Conduction Paths.—On the basis of spinal lesions and excisions, the touch nerve tracts have been located ventrally, pain dorsally, and temperature intermediately in the spinal cord. Apparently the same neurons may supply more than one type of sense organ. Therefore it is sometimes assumed that the fibers are nonspecific, and that specificity is a function of the end organ. Two theories exist as to the specificity of the fibers; (1) that there are four specific paths, and (2) that there are only two, a protopathic and an epicritic system. More will be said later about this latter hypothesis of Head's.

THE EXPERIMENTAL FACTS OF CUTANEOUS EXPERIENCE

The Qualia.—Many complex experiences are derived from the skin, as tickle, shudder, thrill, etc., but non-cutaneous sensations, as kinaesthesis, and deep sensitivity, are involved in them, and careful analysis reveals only four elementary qualia, or modalities: contact, pain, warmth, and cold. Pain is superficial and sharp; contact is dull and somewhat diffuse; warmth is deeply located and very diffuse; cold is condensed, and its apparent locus is midway between pain and warmth.

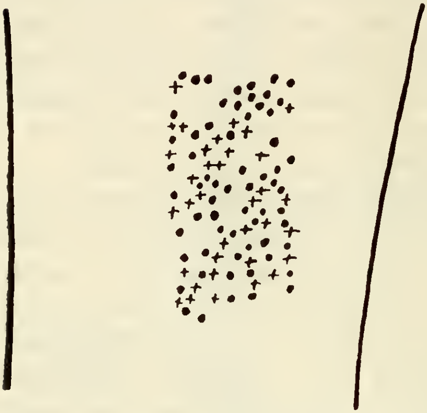


FIG. 23. Punctuate distribution of cutaneous sensitivities

After Von Frey

Regional distribution.—Since the main argument for spatial differentiation of end-organs is the spatial separation of sensitivity, the problem of regional distribution becomes an important one. The most prominent investigators in this field have been Von Frey and Goldscheider.

Punctuate distribution.—A given area of the skin on the back of the hand is explored with punctiform stimuli of the following types:

(1) For contact, an aesthesiometer containing a camel's hair, the length of which can be adjusted to vary the intensity of stimulation.

(2) For pain, an algometer which has a sharp needle-like point mounted in one end, weighted and free sliding, so that a constant pressure is put on the point.

(3) For temperature, metal cylinders, rounded to a dull point at the end, which will hold heat or cold for a short

time. A better device consists of a hollow cylinder through which a current of water, of constant high or low temperature, flows.

It is found that permanent spots exist which respond specifically with the four qualia though often a given spot will respond with all four qualia. With weak stimulation these spots stand out as spacially separate from one another but with strong stimulation they appear as high points of sensitivity surrounded by areas of diminished sensitivity, which merge.

The cold spots will also react to tapping and to warm stimuli; the warm spots to tapping; the contact spots to heat; and pain spots to all strong stimulations.

In general, the pain spots are most numerous, contact next, cold next, and warmth least. This varies, however, with the area tested. Goldscheider gives the following distances between spots.

Touch	Varies from .1 mm. to 1.5 mm. Least at finger tips and greatest on abdomen.
Cold	Varies from .8 mm. to 8.0 mm. Least on palm and abdomen and greatest on forehead and cheek.
Warmth	Varies from 2.0 mm. to 4.0 mm. Least on palm and forearm and greatest on abdomen and chest.

Relative sensitivity of areas.— The absolute intensity limens of the different qualia vary with the region stimulated. They are here arranged in order of increasing intensity threshold: —

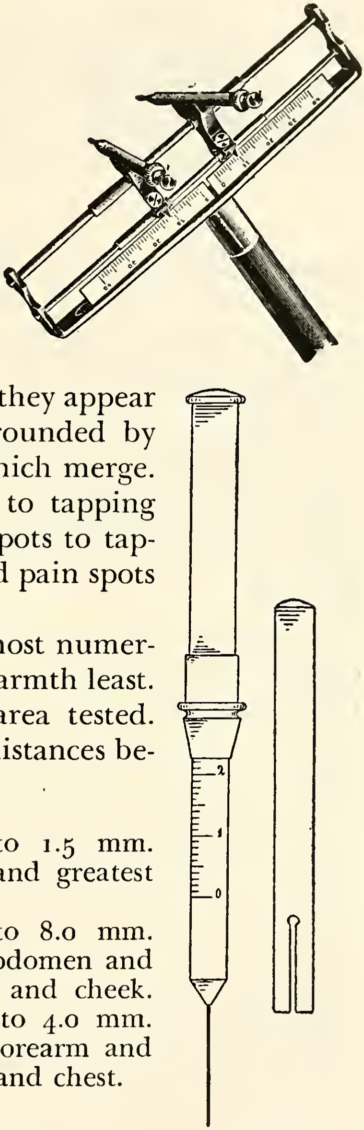


Fig. 24. Two types of aesthesiometer. The upper is for testing the two-point threshold

Courtesy of C. H. Stoelting Co.

	Contact	Pain	Cold	Warm
	Von Frey's results with pressure hairs	*Bernhardt's results with an induction current*	*Weber's results*	
Lowest	Tongue, Nose Lips, Finger-tips, Forehead	Tongue Cheek Back	Loins, Abdomen Nipple Flank Breast	Nipple Loins Eyelid Cheek
Highest	Shin, Sole Back of forearm Loins	Finger Palm Toe-tips	Chin, Palm Finger and Toe-tips	Finger-tips Toes Mouth

Thus the loins have a high limen for contact and a low limen for temperature; whereas the tongue has a low limen for contact and pain, and a high limen for temperature.

The differential intensity limens show a similar variation with region stimulated. Thus the difference limen for contact is small on the lips and tongue and large on the foot. That for temperature is small on the finger and large on the back.

In general, accuracy of localization is good for pain and contact and poorest for warmth. It also varies with the region, so that the forehead and chin are accurate for cold but poor for warmth localization. According to Goldscheider's tables, the cold limen ranges from 0.8 to 3.0 mm. and that for warmth from 2.0 to 5. mm. Related to localization is the *limen for twoness,* or the two-point limen; meaning the distance apart that two stimulus points may be, when simultaneously applied to a given region of the skin, and still be judged as one point. The limen is large for the back and thighs and small for the finger tips. The instrument for securing these limens is the aesthesiometer, consisting of two points whose distance apart may be adjusted along a scale calibrated in fractions of a millimeter. The technique used is similar to that for establishing limens in other sense fields — i.e., the psychophysical method of minimal changes.

The following areas are only sensitive to certain qualia:

Kiesow's area on the inside of the cheek, opposite the upper molars, lacks pain, though the extent varies.

The Cornea and Conjunctiva of the upper lid lack contact, and warmth, though the cornea is highly sensitive to pain.

The Glans penis lacks touch but is rich in pain.
The Tooth pulp responds only with pain and touch.

The reaction times differ for the different qualia. Pain has the longest latent time, the order of speed being, according to Schiff, touch, cold, warmth, and pain.

Drug Selectivity

The logic involved in the use of drugs in experiments on cutaneous sensations is that, if the drugs are found to act differentially, destroying certain qualia and not others, a functional independence of the processes is thereby demonstrated. And a functional independence implies some sort of anatomical separation. Actually observers disagree as to the effects of drugs. Some report selective anaesthesia, while others report that all modalities disappear, but in a definite order. The strength of the drug used accounts for some differences. Moreover the same drug acts differently on different regions.

Cocaine and chloroform destroy, in order, temperature, touch, pain, on the tongue; on the eye and throat only pain and contact are destroyed.

Ethyl Chloride and Ether destroy all qualia, but in a definite temporal order.

Carbolic Acid destroys touch, but not always pain.

The general conclusion from these drug experiments is that the qualia behave in a functionally independent manner.

Disease Effects

(a) Functional dissociations, such as occur in hystericals, and under hypnotic suggestion, give anaesthesias or hyperaesthesias in all combinations, thereby corroborating the drug results.

(b) Lesions in the spinal cord due to traumatic injuries and to diseases like tabes dorsalis, etc., produce all combinations of anaesthesia. Pain and temperature may disappear with touch intact. Contact and temperature may be lost, leaving pain alone, which would be impossible on an intensity theory. It is interesting that cutaneous and organic pain disappear together.

(c) Cases are reported of persons who never experienced pain, though other senses were present. This casts doubt on the theory that pain is merely "intense sensation."

Excision Experiments

Experiment of Schiff. — When the spinal cord was sectioned in the anterior region, leaving only the posterior columns intact, pain disappeared, both cutaneous and intraorganic; but the other qualia remained. Sectioning of the posterior region, leaving intact only the ventral columns and gray matter, produced loss of touch and temperature, with pain intact.

Experiments of Head and Rivers. — The main experiment on which the Head theory of protopathic and epicritic sensitivity was based was that performed by Head on himself. He sectioned a branch of a cutaneous nerve, innervating a region of the hand and forearm. The region was explored for sensitivity previous to the operation, and at regular intervals during the recovery period. The stages of recovery for a specific region are given below, as compiled by Carr. The days represent the amount of time elapsing after the operation before the first reappearance of each of the functions tested.

FUNCTION	DATE OF APPEARANCE	THEORETICAL SYSTEM OF HEAD
Pain	56 days	
Hair sensitivity	86 days	
Extreme cold (26 degrees C. and below)	112 days	Protopathic
Extreme warmth (37 degrees C. and above)	161 days	
Contact	365 days	
Medium warmth	407 days	Epicritic
Medium cold	440 (?) days	

Head concluded on the basis of this and other clinical evidence from patients that there are two distinct kinds of afferent fibers innervating the skin which constitute two distinct systems. One system, which mediates pain, hair sensitivity and extreme cold and extreme warmth, is assumed to be more primitive, more widely distributed, and to regenerate more quickly. It is therefore called the *Protopathic System.* The other mediates contact, and medium warmth and cold. It is assumed to be phylogenetically younger, to be absent from the viscera and certain skin regions, and to regenerate more slowly. It is called the epicritic system. For, whereas the protopathic system is assumed to have a constant recovery time for all the affected parts, regardless of their distance from the point of sectioning, the recovery time of the epicritic fibers varies with their distance from the section. However, Head agrees with the traditional theory of four distinct spinal pathways: one for pain, one for contact, one for cold and one for warm, based on findings in cases of spinal disease.

Head gives certain additional evidence for his theory: (1) The existence of a marginal zone or area outside the anaesthetic area in which protopathic sensitivity was claimed to appear. (2) The alleged protopathic sensitivity of the viscera and glans penis in accordance with observations of hospital patients. (3) The Horsley Case, in which the removal of a brain tumor caused loss of sensitivity of the protopathic type.

Carr has criticized the Head theory on the ground that the published evidence does not support the two main assumptions of the theory; i.e., that the various qualities fall into two independently variable groups, and that within these two groups all functions invariably occur together. For example, Head's own marginal area lacked all temperature sense. Moreover, certain regions, as Kiesow's area, the cornea, the tooth pulp, and the conjunctiva possess certain epicritic and certain protopathic qualia, but also lack certain functions from each group. The only area agreeing with Head's assumption is the viscera, and even here there is disagreement amongst observers. The Head experiment has been repeated since, notably by Boring and by Dallenbach on themselves, and their results have been interpreted as corroborating Head in the main. But Trotter and Davies, who sectioned seven nerves in succession in the same individual, found only the four traditional sensory functions which recovered at approximately the same times, in the order touch, pain and cold, and then warmth. They consider that the evidence demands four peripheral mechanisms.

Theories of Cutaneous Sensitivity

As to cutaneous sensitivity in general, theories are divided between the older conception of a uniform sensitivity of the skin mediated by one common neural mechanism, capable of functioning differentially to produce the four different qualia; and the later conception of four distinct types of end-organ. The former view has recently been revived by Nafe (largely on the basis of Adrian's findings on action currents from cutaneous nerves stimulated at different intensities) as a *quantitative theory*. Nafe assumes that the qualitative differences reported in cutaneous experience are all quantitative differences, along an intensity continuum. They are based on amount of stimulation and resulting frequency of impulses in the nerve. Nafe therefore postulates four attributes of feeling: intensity, density, extensity, and duration, all dependent on the strength or length of the nerve stimulation, or the number of fibers stimulated.

In opposition to this, the *qualitative theories* postulate spatial distribution of four distinct end-organs corresponding to the four cutaneous qualia. The chief evidence is the detailed findings of Von Frey, Goldscheider, and many others with regard to punctuate distribution of sensitivity and its correlation with underlying structures. Fully as convincing are the results of drug experiments pointing toward independent variability; the findings in the case of spinal lesions and peripheral nerve excisions; and the discovery of areas which respond with only certain qualia to the exclusion of others. Later findings fail to corroborate the correlations between specific spots and specific end-organs in the case of cold and warmth, and in the case of contact different structures have to be postulated to take care of hairy and hairless regions respectively. But the total absence of certain qualia in given regions, and the selective action of drugs and disease, are hard to explain except in terms of anatomical independence.

There are rival theories with respect to the particular functions, temperature and pain, which should be mentioned.

Temperature. — The older conception was of a single end-organ for temperature, capable of reacting in two antagonistic ways. Hering postulated one end-organ with two physiological processes in it — assimilation and dissimilation, or anabolism and katabolism, in the manner of his visual theory. The more recent conception is of two distinct types of organ, sensitive to different degrees of the stimulus.

Pain. — Pain has been variously considered as (1) an affective reaction of extreme disagreeableness; as (2) merely the result of the excessive stimulation of any sense organ, or of any cutaneous, kinaesthetic, or intraorganic end-organ; and (3) as a sensation with its own specific organs.

In support of the latter theory, may be quoted (1) the painless cheek area; (2) the fact that other sense organs giving pain have cutaneous organs in them; (3) areas which give only pain; (4) analgesia of some touch and temperature spots; (5) the existence of pain in absence of the other senses in the viscera; and (6) the order of disappearance of pain in drug anaesthesia. The experiencing of pain with overstimulation of other senses can be explained as due to a higher limen for the pain organs lying in the regions under stimulation. On the other hand, there have been found regions exhibiting hyperalgesia for one kind of stimulus with analgesia for others. This is difficult to explain on any theory.

The evidence thus far available seems to favor anatomical differentiation of nerve endings; but the particular organs involved have not yet been satisfactorily identified.

REFERENCES

Adrian, E. D., & Zotterman, Y. The impulses produced by sensory nerve endings, Part 2. *J. Physiol.*, 1926, 61, 151–171; Part 3, 465–483.

Boring, E. G. Cutaneous sensation after nerve-division. *Quar. J. Exper. Physiol.*, 1916, 10, 1–95.

Carr, H. Head's theory of cutaneous sensitivity. *Psychol. Rev.*, 1916, 23, 262–278.

Dallenbach, K. M. Nerve regeneration: the two-point limen. *Psychol. Bull.*, 1931, 28, 214.

Dallenbach, K. M. The temperature spots and endorgans. *Amer. J. Psychol.*, 1927, 39, 402–427.

Goldscheider, A. Physiologie der Hautsinnesnerven. Leipzig: J. A. Barth. 1898.

Head, H., and Rivers, W. H. R. A human experiment in nerve division. *Brain*, 1908, 31, 323–450.

Hering, E. Hermann's "Handbuch." Leipzig. 1880. Bd. iii, Abth. 2.

Kiesow, F. Psychologie des Geschmacksinnes. German Monographs, Taste and Smell, Vo. I, No. 2. Separatabdruck aus Wundt, Philos. Studien. Bd. 3, Heft. 329–368.

Nafe, J. P. The sense of feeling. Chap. 9 in Murchison's *Foundations of Experimental Psychol.*, p. 395.

Schiff, P. Lehrbuch der Physiologie. 1858.

Trotter, W., and Davies, H. M. Experimental studies in the innervation of the skin. *J. Physiol.*, 1909, 38, 134–246.

Von Frey, M. Beiträge zur Sinnesphysiologie der Haut. Leipzig. 1895.

Von Frey, M. Untersuchungen über die Sinnesfunctionen des Menschlichen Haut. Leipzig: Bei's Hirzel. 1896.

Weber, E. H. Die Lehre vom Tastsinne und Gemeingefühle. Braunschweig: 1851. Verlag von Friedrich Vieweg und Sohn.

CHAPTER V

OTHER SENSORY PROCESSES

BY their very nature the other types of sensitivity are less subject to careful quantitative experiment than the preceding. Their importance, however, warrants a brief exposition. They may be conveniently grouped into three divisions, the gustatory and olfactory senses, the labyrinthine and kinaesthetic processes, and the intraorganic groups.

GUSTATION AND OLFACTION

THESE two senses are closely related in perception. Many sensations attributed to taste are actually odors. This confusion is due to the nearness of the nose and mouth and the fact that the same object stimulates both senses simultaneously, i.e., when food is entering the mouth. Many foods are pronounced tasteless when olfaction has been eliminated. Of the two senses, the more exact information is available with regard to gustation.

Gustation

The organs of taste are located on the sides, tip and base of the tongue, the soft palate and the pillars of fauces. Since the tongue also contains kinaesthetic and cutaneous organs, the sensations from food stimuli are complex, and careful experimental controls must be used to isolate the purely gustatory components. The taste organs proper — the taste buds — are located in the papillae, raised mushroom-like spots surrounded by deep grooves in which saliva collects. Three types of papilla are distinguished: the fungiform, or small red type on the tip and sides of the tongue; the circumvallate, near the base, and much larger; and the filiform. Only the first two types actually function. The taste buds are arranged along the sides of the deep grooves, as many as five to a papilla, and are consequently bathed in saliva. The bud consists of a sac containing a taste pore. In its center are rod shaped taste cells with hairs projecting out into the saliva.

The innervation of the taste organs is complicated by the fact that the main nerve trunks also carry other components. For example, the IXth glossopharyngeal nerve which innervates the base of the tongue, carries, beside the gustatory fibers, secretory, trophic, motor, and cutaneous fibers. The intermediate branch of the facial nerve, the VIIth, which innervates the front and middle portions of the tongue, carries gustatory, secretory, and trophic fibers. The taste buds in the throat are innervated by the Xth or vagus nerve. The first center for the taste nerves is the nucleus of the fasciculus solitarius in the medulla. The cerebral terminations are unknown but probably lie in the hippocampal gyrus.

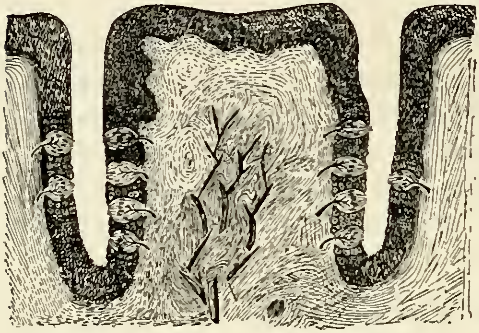


FIG. 25. Organ of taste. Papilla with taste buds

That these are the taste nerves is proved by their peripheral endings at the taste buds and the fact that the taste buds degenerate when these nerves are excised. The taste function is confined to regions where the taste buds lie. The adequate stimulus for taste is a substance in chemical solution in contact with the taste pores in the papillae. Substances are tasteless unless in solution. There is a close, though not perfect, correlation between the chemical composition of substances and their taste; i.e. acids are sour, and a sour taste usually shows the presence of an acid. But salts may be sweet, salt or bitter.

The Phenomena of Taste. — As with the other sensory processes, some of the facts about taste point to an independence of the four gustatory qualia, salt, bitter, sour, and sweet, while other facts suggest dependence or mutual interaction.

The independent variability of the taste qualities. — First, it is possible to analyze four distinct qualities out of the complex taste experiences. To do this experimentally necessitates blindfolding the subject and clamping the nose. It also requires removing or holding constant all other sensory factors, as cutaneous and kinaesthetic experiences from the mouth. To make contact uniform, a solution is employed. It is applied only to a small part of the tongue surface. The temperature is made equal to the mouth's temperature. Tongue movements are eliminated. The mouth is washed with distilled water after each stimulation.

Second, all the complex tastes, like metallic, etc. can be synthesized by properly combining the four qualities. Metallic taste is a complex of salt and sour.

Third, for each taste quality, a region or regions can be found in which that taste is the strongest or sole response. The tip of the tongue gives salt and sweet; the sides give sour and the base bitter. Moreover, the sensation obtained is a result of the area stimulated. The same stimulus will give different sensations on different areas. For example, magnesium sulphate is sweet or acid at the tip and bitter at the base of the tongue. Sodium sulphate is salt at the tip and bitter at the root. Mechanical stimulators and electrical stimulators produce sensations which vary with the region stimulated.

Systematic stimulation of 125 isolated papillae by Oehrwall gave the following results for the different qualia:

27 papillae gave no response
60 papillae gave 3 qualia
12 papillae gave sweet and sour
4 papillae gave sweet and bitter
7 papillae gave bitter and sour
12 papillae gave sour only
3 papillae gave sweet only
0 papillae gave bitter only

This shows that the specificity is partly a function of the region and partly a function of the papillae; but in the last analysis is probably a function of the particular taste bud affected and there may be more than one type of taste bud in a single papilla. The extreme difficulty of stimulating one isolated papilla is obvious.

Another evidence of independent variability is the behavior of the four qualia under drugs. Some drugs remove some qualia and not others, while all drugs tend to affect them in temporal order. Thus cocaine causes increased sensitivity to acid, then destruction of pain, bitter, sweet, salt, sour, and touch. While gymnemic acid removes sweet and then bitter, but does not affect acid and salt.

Moreover, the different qualia have different temporal and intensity thresholds, though this may not reside in the sense organs.

Facts pointing to interaction of qualia. — Two phenomena of taste show dependent variation of the qualities — contrast and mixture. Contrast effects are both simultaneous and successive.

Contrast. — Salt causes distilled water applied to a neighboring area to taste bitter or sweet. Sweet causes it to taste bitter or salt. Intensity changes also occur. For example, salt increases the intensity of sweet and sour; sour of sweet and salt; and sweet of salt and sour. On the other hand some tastes inhibit others.

Mixture. — When tastes are mixed, there may occur suppression of one component, as of bitter by sweet, in coffee; or mutual suppression; or rivalry; or new compounds in which the components are unrecognizable. It is necessary, of course, to rule out chemical mixture of the stimuli, in considering new compound tastes.

The Gustatory Theory. — The one theory advanced for gustation is that the four qualia are mediated by anatomically distinct sense organs, the taste buds, spatially separated from one another, and, hence, not interacting directly. The theory accounts for everything except the facts of contrast and mixture, but these can be accounted for on cortical grounds.

Olfaction

The sense organ for smell is an area about 500 square millimeters in size located in the roof of each nasal cavity. It differs from the surrounding mucous membrane in being thicker, yellowish in color, and moistened by a peculiar secretion. A minute examination of the membrane shows it to contain the cell bodies whose unmyelinated axones form the olfactory nerves terminating in the olfactory lobes. The cell bodies contain rods with hairs at the end projecting to the surface of the membrane. The olfactory cells, unlike those of the other sense organs, except vision, are modified bipolar neurones.

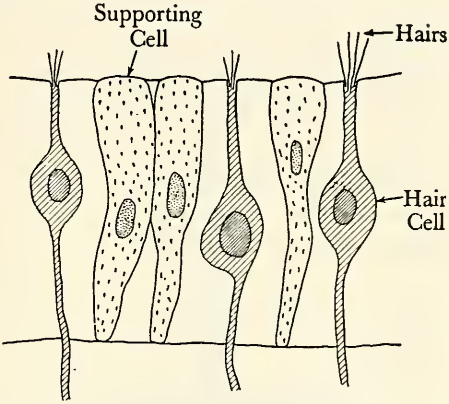


FIG. 26. Cells of olfactory membrane

The adequate stimulus to smell is odoriferous particles diffused through the air and dissolved in the secretion which bathes the olfactory membrane. If the secretion dries, smell is impossible. There is a slight, but imperfect, correlation between the chemical composition of substances and their odor, so that smell is classed as a chemical sense. Electrical currents are an inadequate stimulus to smell. Mechanical stimulation has not been demonstrated to be effective.

The Experimental Facts. — Less is known about olfaction than about any other external sense because of the inaccessibility of the organ, which prevents systematic exploration, and on account of the great complexity of the experiences themselves. Many odors contain cutaneous elements, as ammonia; or organic reflexes as in the so-called nauseating odors; or kinaesthetic elements involved in the act of smelling. Taste has been shown to be confused with odor. And the confusion between the sensory qualities of odors and their affective tones is greater than in the case of other senses.

Finally, odors are extremely unstable and are rapidly adapted to. Nor can they be tied down to perceptual objects as can visual sensations.

As a result the analytical techniques used in other sense fields are inapplicable. For example, regional exploration which is used so effectively in cutaneous experiments is impossible. It cannot be determined whether different areas of the olfactory membrane react to different qualities. The stimuli cannot be carefully manipulated as in vision because they are gaseous. However, there are certain analytical techniques which can be used to demonstrate both independence and interaction of the qualia.

The method of exhaustion. — Due to the rapidity of adaptation to a given odor it is possible to split up complex odors into their component elements by systematically adapting out each of the components. For example, if adaptation to one odor causes some other odor to be altered, the first is shown to be a component in the second. And if the second disappears completely, either it is identical with the first or a component of it. If no effect occurs, the two odors are independent, having no common elements.

The method of adaptation change. — Since different odors have different speeds of adaptation, any complex odor should change its quality after a period of adaptation, due to the lowered sensitivity to some of its components relative to others. Therefore if an odor does not change it is simple. And if it does, the character of the changes will disclose the components. The objection to the method is the rapidity with which the changes occur.

The method of selective anaesthesia. — If the subject is rendered anosmic by drugs, the different odors have different recovery rates, as do cutaneous qualia. But it is not possible to destroy certain odors and leave others intact.

Disease effects. — Some diseases act selectively on smell, eliminating certain odors, but the effects are highly individual and yield no systematic data.

Mutual interaction of the qualia can be demonstrated in two ways, by mixture of odors or by contrast.

Mixture of odors. — The result may be either suppression of one or both components, or rivalry, or decrease in intensity of one or both, or a new odor may result from the mixture. Here, as in taste, it is necessary to rule out direct chemical mixture of the stimuli.

Contrast. — One stimulus may be given to one nostril, the other to the other, or they may be given successively in time to the same nostril. Changes in intensity of the response can be obtained, though this is true between all the qualia, not between certain ones, as in vision, and hence is not qualitative contrast.

The Olfactory Theories. — One of the chief experimentalists in the field is Zwaardemaker. He devised an instrument for controlled presentation of olfactory stimuli, which is widely used, called the olfactometer. There are two tubes mounted in a frame. One end of each tube is curved up to fit into the nostril. The other end projects straight out so that another tube of larger size can be fitted over it. The larger tube is lined with the odoriferous substance. The intensity of the stimulus is directly proportional to the area of the outer tube which is exposed beyond the inner, since it determines how saturated the air in the inner tube will be with odoriferous particles.

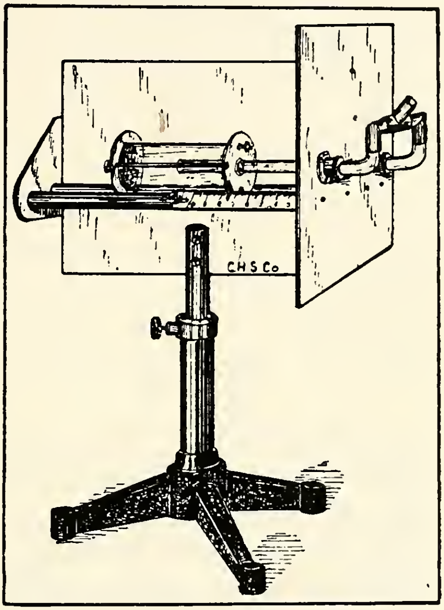


FIG. 27. Zwaardemaker's Olfactometer

Courtesy of C. H. Stoelting Co.

Zwaardemaker isolated nine distinct sense qualities for smell. They are (1) the ethereal smells, (2) the aromatics, (3) the balsamics, (4) amber-musk smells, (5) allyl-cacodyl smells, (6) burning smells, (7) caprylic smells, (8) repulsive smells, and (9) nauseating smells. Zwaardemaker suggested that there are nine end-organ mechanisms corresponding to his nine qualities. These he assumes are spatially separated so that the anterior region responds to food stimuli; the posterior region to nauseating stimuli, and the middle region to the sexual stimuli, producing the caprylic odors. He also assumed that stimulation of neighboring areas produced mixed sensations, whereas stimulation of remote areas caused rivalry or compensatory effects.

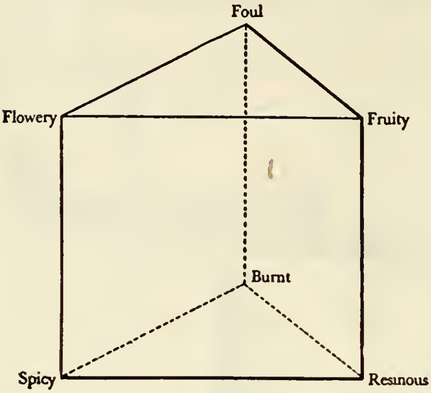


Fig. 28. Henning's olfactory prism

There are several objections to Zwaardemaker's qualia and to his theory. First, some of his distinctions are not made on an olfactory basis. The so-called repulsive odors are named from their affective tone. The nauseating smells are characterized by the oesophagial reactions they excite. The burning smells, at least benzol and phenol, are characterized by their cutaneous component. Second, the evidence for spatial differentiation is inadequate. And finally, Nagel has shown by fatigue tests that identical odors may be excited by different end-organs.

Attempts have been made to construct a geometrical figure which will express the interrelations of the olfactory qualities. An example is Hans Henning's olfactory prism; a figure with triangular bases and perpendicular sides, as in Figure 28.

LABYRINTHINE AND KINAESTHETIC SENSES

These are commonly classed together as representatives of the proprioceptive groups — the sensations which inform us of the position and movements of our bodies. Unlike the other special senses, the proprioceptive group do not give rise to experiences which are acutely conscious or figure in attentive thought. The stimulation of these organs arouses appropriate adjustive behavior on a more or less subconscious level. In fact there is probably no direct excitation of cerebral patterns by the labyrinthine stimulations. The vestibular nerve tract terminates in the cerebellum and has no important cortical connections. It is evident then that whatever sensory experiences it gives rise to are indirectly excited through the adjustive motor acts which are initiated.

The Labyrinthine Apparatus. — This consists of the semicircular canals, the saccule and the utricle, all of which are parts of the same membranous labyrinth as the cochlea, and are in the inner ear. The membranous labyrinth lies somewhat loosely in a bony labyrinth of the same shape. The space between is filled with the perilymph. The canals of the membranous labyrinth are also filled with a liquid — the endolymph. The three canals are arranged in such a way that each lies in a different plane so that in whichever direction the head is moved, one of the canals is stimulated. The inner surface of the canals is lined with cilia, or hairs, extending into the liquid. The assumption is that when movement occurs in the plane of the canal the liquid is forced in the direction opposite to the movement because of its inertia, and the resulting pressure on the hairs excites the end-organs. But if the head keeps moving at a continuous uniform rate in the same direction, the perilymph no longer moves opposite to the canal but with it, so that no stimulation occurs. If, now, the head stops moving, the momentum of the perilymph will force it ahead and the hair cells will again be stimulated. Thus the canals, according to the Mach-Breuer-Brown theory, acquaint us with the beginning and end of the movement and of any sudden change in rate of movement. Herrick points out that the very minute size of the canal would prevent any large motion of the liquid and that the stimulation must be due to the slight motion occurring at the moment the head movement takes place. The three canals all communicate at both ends with the

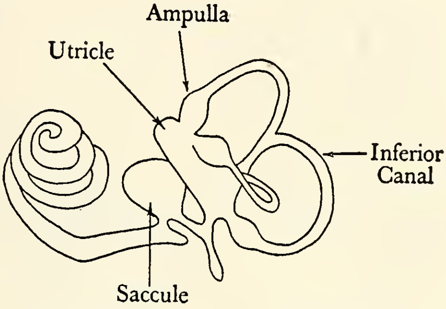


FIG. 29. The vestibular apparatus

utricle, a sac at their base. At one end of each canal there is an enlargement, the ampulla, containing sensory epithelium. These ampullae contain the cell bodies of the nerves which communicate with the hair cells of the canals. Beneath the utricle is the saccule, connected with it by a narrow duct. Both saccule and utricle contain sensory epithelium. The otolith organs lying within are supposed to move in such a way as to press on the hair cells lining the sacs, thus initiating impulses which are interpreted as change in position, or as movement of the head, depending on the sort of stimulation which is being simultaneously received from the canals. The maculae are assumed to favor horizontal and prevent vertical movements of the otoliths.

The Phenomena of Labyrinthine Sensitivity. — As nearly as can be determined, the adequate stimulus to the labyrinthine organ is either acceleration or retardation of rotary motion in any plane. Whether linear acceleration or retardation is an adequate stimulus is still undecided. But in addition there are several inadequate stimuli. Galvanic stimuli, that is, very weak electric currents passed through the head, excite the organ, the nature of the excitation depending on the direction of the current. Irrigation of the ear with hot or cold water, called "caloric" stimulation, excites the organ as does also pressure of air from the external meatus, in subjects who have a fistula into the inner ear.

The experimentation on the labyrinthine sense utilizes several methods.

Rotation of the body. — The typical psychological method is to rotate the subject in a chair designed for the purpose. An early model was devised by Sanford and more adequate types have been developed by Dodge and by Dunlap. During the war, the necessity of testing aviators for capacity to orient themselves in the absence of visual cues promoted much study of the problem of adequate apparatus. The revolving chair must be motor driven and yet noiseless and capable of having its speed varied at will. As far as possible all other cues must be strictly controlled.

Data obtained may be of various sorts. The subject may introspect, while being rotated, to describe any experiences directly or indirectly aroused; or he may be asked to make localizing judgments with reference to his probable position at any moment; or objective records may be made of the reflex adjustments resulting from the vestibular stimulation. Among these an important one is the corrective movements of the eyes in a direction opposite to that of rotation, the effect of which is to keep the fixation point of the eyes constant with reference to the stationary background of the visual field. These movements are called nystagmus. Dodge has given considerable attention to post-rotation nystagmus and has recorded the eye movements photographically. After rotation of the body ceases, the eyes continue for a time to make these compensatory movements, which cause the visual background to appear to continue moving.

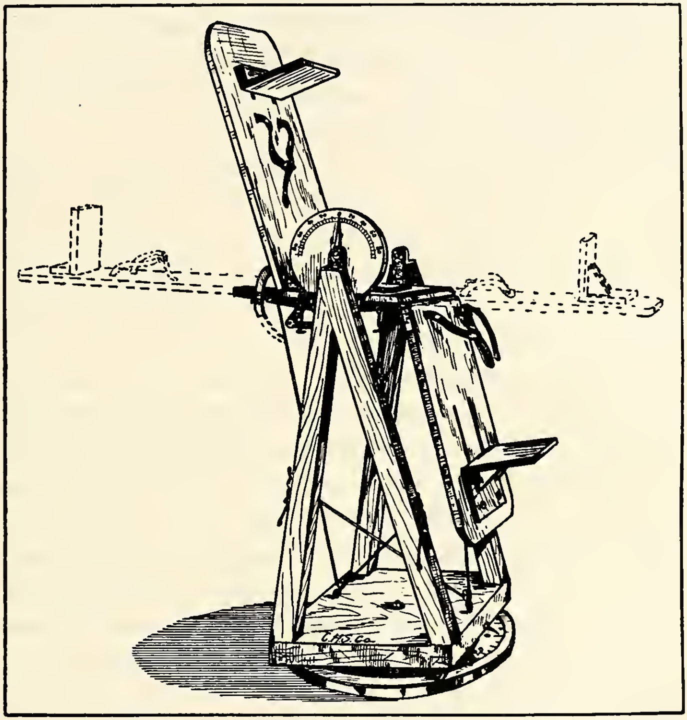


Fig. 30. Rotation and tip table

Courtesy of C. H. Stoelting Co.

Study of abnormal nystagmus movements. — In cases of pathological conditions of the labyrinth or neural connections, a correlation can be found between the character of the behavior symptoms, especially the eye movements, and the nature of the lesions. Alterations in experience also can be introspectively observed. For example, in Ménière's disease, which alters the functioning of the semicircular canals, there is considerable giddiness. And in deaf mutes where canals have later been found by autopsy to be defective, no giddiness resulted from bodily rotation, and nystagmus was absent. These cases also showed lack of ability to maintain balance with eyes closed.

Experiments on animals. — Extirpation of the vestibular organs, as well as the substitution of various inadequate stimuli for the adequate stimulus, such as pressure, artificial otoliths, galvanic currents, etc., have yielded some valuable knowledge. The behavior in cases of unilateral disturbance of the organs is significant.

Experimental stimulation of a single canal causes deviation of the eyes and movements of the head and body in the plane of the canal stimulated. One canal can be extirpated without causing serious disturbance, but if both are removed, uncontrollable movements of the head and eyes and loss of coördination result. Animals, so operated upon, fall about, turn in circles and rotate the eyes constantly, and pigeons are unable to fly properly. Eventually these disturbances disappear but a permanent effect is loss of muscle tone, which lends support to the theory that the equilibratory apparatus functions in maintenance of body tonus.

Effect of practice. — That alteration of the reflex adjustments to labyrinthine stimulation can be produced by continuous use has been demonstrated by the modification of the nystagmus with practice.

The Kinaesthetic Sense

Appreciation of head movements or those of the whole body is contributed by the labyrinth. But sensations of movement of separate limbs or of parts of the body relative to one another are contributed by the kinaesthetic organs lying in the muscles, joints, and tendons.

The end-organ for muscle sensibility is a series of nerve endings among the muscle spindles, which are spirally wound around the fibers, terminating in end plates. The stimulus is muscle contraction. The innervation of the striated muscles is cerebro-spinal, while that for the smooth muscles is sympathetic. Only the kinaesthetic organs of the striated muscles should be classified among the proprioceptors. The end-organs for tendon sensibility are spread over the surface of the tendons in a thick arborization and are stimulated by stretching of the tendon. The organs for joint sensitivity are located in the joints and surrounding tissues. Herrick suggests that they are chiefly Pacinian corpuscles, and hence a part of the general system of deep pressure sense. The adequate stimulus is rotation of the joint.

Kinaesthetic Experiences. — That the sense of movement of limbs is independent of cutaneous sense can be proved, either by the fact that in normal individuals the skin can be anaesthetized without destroying kinaesthetic experiences, or by the fact that loss of kinaesthetic sense, as in locomotor ataxia, is unaccompanied by loss of skin sensitivity. Victims of tabes dorsalis are unable to tell, with eyes shut, how far their limbs have been passively moved or in what direction, and they cannot coördinate their active movements or estimate the position of their limbs.

The relative importance of muscle sense as compared with joint sense has been tested in different situations. It is found that a faradic current passed through a joint causes judgments of small movements of that member to be considerably less accurate. Myers reports that if a movement of the first interphalangeal joint through a $\frac{1}{2}$ degree arc is just perceptible under normal conditions, then the threshold will be raised to as high as $3\frac{1}{2}$ degrees when a current is passed through the joint. And finger movements produced under these experimental conditions are jerky. Movements of jointless members, such as tongue and eyeballs, are very poorly judged in the absence of other cues even though the muscle sense is present.

At least four different attributes of kinaesthetic sensations can probably be distinguished: intensity, extensity, duration, and quality. By means of these attributes, the speed and extent of movements can be judged, and the particular limb moved can be identified. Illusions of extent of movement result from variations of speed. Slow movements are overestimated as to length.

Judgments of weight. — In weight-lifting experiments, kinaesthesis is undoubtedly the main cue, but in this case it is the muscle and tendon components that play the chief rôle. The tension necessary to hold up the weight must be finely adjusted to the load and the accuracy of such judgments attests the importance of the cue of muscle and tendon strain.

Awareness of position. — It has been pointed out by Myers that awareness of movement and awareness of stationary position of the limbs are two different things. The latter he designates " stataesthetic " sense as opposed to kinaesthetic. Probably when accessory cues from other sense organs are eliminated, the awareness of position is poorly defined, but states of contraction of the various muscles form an important part.

Experiments on Kinaesthesis. — Very little work has been done with the kinaesthetic sense considering its importance for motor psychology. Some of the problems which have been attacked are the following: (1) ability to judge weights by lifting; (2) the basis of the sense of effort in active movement as compared with passive movement; (3) the absolute threshold for awareness of movement, or of change of movement, and the differential threshold for varying rates and distances of movement.

Experiments in judging weights have been used primarily to illustrate the psychophysical methods or to demonstrate Weber's law, but the results incidentally yield quantitative data about kinaesthetic experience. Judgments of weight are obviously based on quantitative variation in the experience of muscular strain or resistance accompanying lifting. In this sense it is possible to speak of differential thresholds of intensity for kinaesthesis, and of an intensity series which follows the logarithmic function. The procedure is to have a series of variable weights and a standard. The standard is presented with each of the variables and judgments of lighter or heavier are obtained.

To determine thresholds for appreciation of movement, it is necessary to hold all members, except the one to be moved, rigid, and then the member, for example the finger, is passively moved through a given arc. If the whole arm is to be moved, a track or slot is used with a car which moves along it, which the subject grasps. Comparisons between active and passive movement sensations can be introspectively obtained.

INTRAORGANIC SENSITIVITY

The extreme difficulties in the way of a study of the intraorganic senses prevents the obtaining of accurate information either about the organs, or the exact manner of their stimulation, or the sensations which result. Two types of intraorganic sensitivity have been carefully investigated — hunger and thirst. These will be discussed first.

Hunger. — Experiments of Carlson and Cannon have determined the main cause of hunger. A distinction must be made between hunger as a specific sensation and particular longings for certain foods. The latter type of experience is apparently the result of conditioning from past experience and is a learned reaction. However even this sort of appetite may yet be shown to have a specific biochemical basis. An example is the peculiar food longings of pregnant women.

Hunger pangs have been shown to be rhythmically recurring sensations caused by the contractions of the walls of the stomach when it is empty. Peristalsis is a rhythmic contraction of the walls of the digestive organs, and occurs normally when food is present in them. But the contractions which occur on an empty stomach are more violent. The resulting stimulation of the kinaesthetic receptors in the smooth muscle walls causes the pangs which are introspectively reported. Two rival theories were originally advanced, one that the experience results from a general condition of the tissues which, through the altered character of the blood stream, stimulates the brain directly and the other that it is a specific oesophageal sensation. The weight of evidence against any such change in the blood's composition and against direct chemical stimulation of the brain, and the weight of Cannon's and Carlson's experimental evidence in favor of a local oesophageal origin seem convincing. Cannon introducted into the empty stomach of a subject a rubber balloon, with tube extending from the mouth, connected with a marey tambour and kymographic recording device. The subject was supplied with a response key so that he could signal when he experienced hunger pangs. In this way he found that powerful contractions occurred and that these were accompanied by simultaneous hunger sensations. Carlson worked with a subject who had a gastric fistula. Stimulation of the stomach by rubbing the mucosa or distending it with a balloon did not produce the sensation, unless it caused the muscular contractions. Carlson has shown in experiments on animals and human subjects that hunger begins with weak contractions which become more violent until they may terminate in a spasm of the muscle. Various stimuli cause a cessation of the contractions, as chewing, swallowing, smoking, and a sudden emotional stimulus. The direct cause of the contractions is still un-

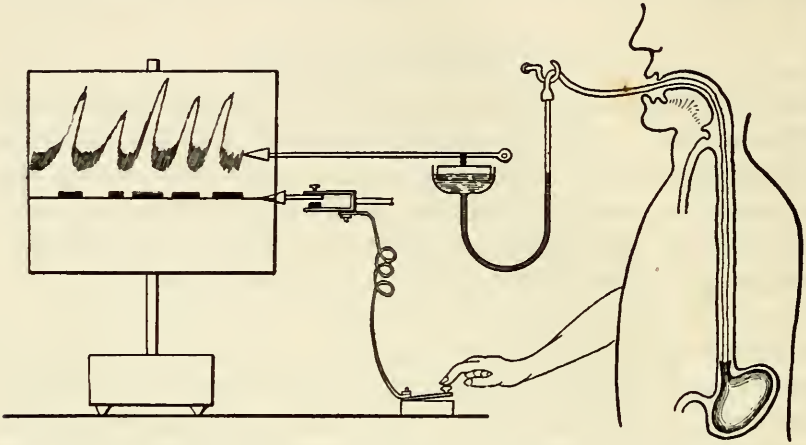


FIG. 31. Apparatus for studying hunger. The subject presses the key when he feels the hunger pangs

After Cannon in Murchison's *Foundations of Experimental Psychology,* p. 437, Fig. 1.

determined but it is thought to be a local automatism rather than any general condition such as change in the blood composition.

Thirst. — The immediate sensory basis for the experience of thirst has been demonstrated to be dryness of the mouth and throat, particularly in the region of the palate. This can be demonstrated by the fact that the sensation can be produced by artificially drying the throat membranes and can be removed by wetting them even though no liquid is swallowed. But the cause of the dryness of these membranes in real thirst has been a subject of speculation. One theory attributes it to a general loss of moisture from the body. Evidence in favor of this theory is the thirst produced by profuse sweating, loss of water in diabetes, and by hemorrhages; and the fact that thirst can be relieved almost immediately by injection of water under the skin or into the intestines and by absorption through the pores. It is assumed that when moisture is thus lost from the tissues, it is drawn away from the throat and mouth membranes, with the resultant dryness which gives rise to thirst. An opposed theory attributes the effect to local factors. Cannon, for example, explains thirst in terms of reduced secretion of the salivary glands. If the throat were not bathed with saliva it would always be dry, due to air currents from the nasal cavity. Therefore thirst would occur when the saliva ceased to flow. It has been demonstrated that the rate of secretion of the salivary glands is reduced by general loss of body moisture. Cannon demonstrated a reduction of the salivary flow from 14 cc to less than 8 cc by not drinking from 7:00 P.M. of one day to 3:00 P.M. of the next. As soon as water was again taken, the normal flow of saliva reappeared. The reduced salivary flow was accompanied by thirst. Cannon also found that if the rate of secretion were reduced by injections of atropine, thirst resulted even though no general loss of moisture occurred. In an experiment in which rabbits were deprived of water for days, some of them were given pilocarpine to increase the salivary secretion; others not. When the animals were finally allowed water, only those who had not received the pilocarpine drank freely. Dogs, whose salivary ducts have been tied off are reported to seek water continuously. All these facts, taken together, support the conclusion that thirst is a dryness of the throat membranes caused by a reduced secretion of saliva.

General Intraorganic Sensitivity. — The remaining interoceptive processes are inadequately explored. Herrick recognizes the following:

Organs of nausea, the stimulus to which is an antiperistaltic reflex in the digestive tract.

Organs for respiratory sensations, suffocation, and the like.

Organs for circulatory sensations, flushing, and heart panic.

Organs for sexual excitement.

Kinaesthetic organs for sensations of distention of cavities, stomach, rectum, bladder.

Organs of visceral pain.

Organs of obscure abdominal sensations, probably due to tonic contractions of unstriped muscles, and occurring as an accompaniment of strong emotion.

A well-known fact about visceral sensitivity is that pains whose origin is in certain visceral regions may be falsely perceived as arising from peripheral sources. These are known as referred pains. Thus pains in the forehead may actually arise from constipation, dental caries, gastric dyspepsia or eyestrain; those in other head regions may come from the liver, bladder, or uterus. Pains from the liver may be referred to the right shoulder blade, while ovarian disturbances may give rise to pains perceived as coming from the heels, hips, back, breast or hand. The explanation for these false localizations is apparently that the cell bodies of afferent neurons lie part in spinal ganglia and part in sympathetic ganglia. This makes it possible for afferent fibers from the peripheral sense organs, say of cutaneous sensitivity, to conduct visceral impulses to the central nervous system in addition to their own somatic impulses.

This fact is an interesting sidelight on the problem of specificity of nerve energy. The character of the experience is a function of the region of the brain stimulated rather than of the character of the conducting impulse.

REFERENCES

Boring, E. G. The sensations of the alimentary canal. *Amer. J. Psychol.* 1915, 25, 1–57.

Carlson, A. J. The relation between the contractions of the empty stomach and the sensation of hunger. *Amer. J. Physiol.,* 1912, 31, 175–192.

Cannon, W. B. The physiological basis of thirst. (The Croonian Lecture for 1918.) *Proc. Roy. Soc.,* 1918, Ser. B, 90, 283–301.

Cannon, W. B., & Washburn, A. L. An explanation of hunger. *Amer. J. Physiol.,* 1912, 29, 441–454.

Dimmick, F. L. The investigation of the olfactory qualities. *Psychol. Rev.* 1927, 34, 321–335.

Dodge, R. Habituation to rotation. *J. Exper. Psychol.,* 1923, 6, 1–35.

Dodge, R., & Fox, J. C. Jr. Optic nystagmus: II. Variations in nystagmographic records of eye movement. *Arch. Neur. & Psychiat.,* 1929, 22, 55–74.

Dunlap, K. A rotator for vestibular and organic stimulation. *J. Comp. Psychol.,* 1921, 1, 365–367.

Gilliland, A. R. The taste sensitivity of an anosmic subject. *J. Exper. Psychol.* 1921, 4, 318–326.

Griffith, C. R. An experimental study of dizziness. *J. Exper. Psychol.* 1920, 3, 89–125.

Henning, H. Physiologie und Psychologie des Geschmacks. *Erg. d. Physiol.,* 1921, 19, 1–78.

Herrick, C. J. An introduction to neurology. Phila: W. B. Saunders Co., 1927. 4th ed., pp. 98 ff.

Holsopple, J. Q. Space and the non-auditory labyrinth. Chap. X in Murchison's Foundations of Experimental Psychology.

Mach, E. Grundlinien der Lehre von den Bewegungsenspfindungen. 1875.

Myers, C. S. An introduction to experimental psychology. Cambridge University Press, 1911.

Nagel, W. Vergleichende physiologische und anatomische Untersuchungen über den Geruchs- und Geschmackssinn und ihre Organe. Bibl. Zoöl., 1894. No. 18.

Oehrwall, H. Untersuchungen uber den Geschmackssinn. *Skand. Arch. f. Physiol.,* 1891, 2, 1–69.

Zwaardemaker, H. L'odorat. Paris, 1925.

Zwaardemaker, H. Die Physiologie des Geruchs. Leipzig: W. Engelmann. 1895.

Part Two—The Perceptual Process— Space Perception

CHAPTER VI

VISUAL SPACE: DEPTH AND DISTANCE

THE PERCEPTUAL PROCESS

PERCEPTION differs from the simple sensory process in adding meaning or interpretation to what is immediately given. This meaning is a function of the individual's past experience (i.e., past reactions to the stimulus situation) and hence is a modification of the learning type. There are two important features. (1) One is that the different sense processes become integrated so that they are responded to in a unitary way. Visual, auditory, and tactual elements are grouped into a unitary whole and reacted to as such. This occurs through the establishment of integrated sensory-motor coördinations. Motor tendencies are as much a part of the perceptual process as are the sensory elements. (2) The other important feature is the redintegrative one. When a person has already reacted to a stimulus situation frequently, he thereafter reacts to a part of the situation as he would to the whole. This can be diagrammatically expressed as follows: Let S_1 and S_2 and S_3 and S_4 represent different elements in a stimulus situation which calls out response R. If, later, S_1 is presented, alone or in a new combination, it may be reacted to the same as though S_2 and S_3 and S_4 were present. If a person has frequently read the printed word " psychology," then he will read " pychology " as though it were " psychology." The doctrine has been held that, where perception involves reaction to absent elements in the situation *as though they were present,* these absent elements must be filled in by imagery. Hence perception is considered sensation plus imagery. But there is no evidence to prove that the absent features cannot be reacted to without being imaginally present. Meaning may be present in various forms; in fact a situation can probably be reacted to meaningfully (which implies perception), without any specific representative of the absent features. This problem will be more fully considered in the discussion of meaning.

Since all reactions to stimuli are to some extent modified by experience, it is justly argued that pure sensation never occurs as such and hence is a logical abstraction. All conscious reactions to stimuli are perceptual.

Among the major problems of perception which have been experimentally investigated are the following:

1. To determine the sensory cues involved in the perception of depth, size, shape, distance, direction, motion, weight, time, etc.
2. To determine the factors which affect the efficiency of perception in reading, etc.
3. Abnormalities of perception and their explanation.

The present chapter will be concerned mainly with the first problem as illustrative of the whole field.

PERCEPTION OF SPACE

Localization in space is probably not one of the given characteristics or attributes of our sensory experiences, which they possess natively or antecedent to our reactions with our environment. Spatial localization is an acquired feature of experience which must be built up by achieving the cooperation of the sense organs and muscles in the process of overtly manipulating the environment in securing ends. Therefore, the problem of space perception is the problem of determining by what combination of sensory cues the various spatial characteristics of objects are perceptually apprehended.

A distinction must be made between physical space and perceptual space. The former has to do with the assumed real location of objects with reference to one another in a physical framework of space and time. On the other hand perceptual space is concerned with the locations (and other spatial attributes) which our perceptual experiences acquire as a result of our attempts to achieve coöperation with the environment. For example, in the case of after images, in so far as they are physical events, they are physically located in the retina and brain. But in terms of perceptual space, they are located where we perceive them, usually out in front of us. Entoptic phenomena are perceived by us as located at some distance in front of us, yet physically they are in the eye. A good proof of the fact that the perceptual location of objects is acquired and not natively given is to be found in the introspective reports of subjects who have been operated on for congenital cataract. Cases described by Miner, Latta, and others show that depth and distance are features which are lacking in the first visual experiences of such subjects in adult life and are acquired by reacting to environmental objects. Miner found binocular fusion entirely lacking in a 22-year-old girl for a time after operation; but fusion was gradually acquired by learning so that normal stereoscopic sight was possible with depth appreciation.

Since perceptual space and physical space are not identical, and since perceptual space is built up in the process of achieving coöperation between the senses, it follows that the final criterion of correct spatial localization of our percepts is not to be found in any identity or correspondence between perceptual and physical loci, but is solely the pragmatic criterion of coöperation. Can sensory and motor systems cooperate in carrying out successful adjustments? If so, localization is correct. Some classical problems of space perception which have caused difficulty can be answered in these terms. For example, take the problem as to whether we originally, in infancy, perceived sensory stimuli as localized in the head or body and later projected them outward. Since no localization precedes reaction to the environment, it is evident that we do not first localize in the head and then project outward, but rather that exact localization is gradually built up in the process of reaction, and is the end product of a long period of learning. After that, of course, wrong localization may occur through a misinterpretation of sensory cues, as in the case of referred pain, or in watching the performance of a ventriloquist. But wrong localization, just as much as correct localization, requires that a system shall have been established already as a result of past experience.

Another classical problem is that of how we perceive objects " right-side-up " when the image of these objects on the retina is physically reversed by refraction so that it is " up-side-down "? Why do we not perceive objects as being up-side-down? The accompanying diagram, Figure 32, shows that there is a physical reversal of the image on the retina, due to the refraction of the rays of light by the eye. The ray from a is conducted to a point a′ on the retina, while the ray from b is conducted to the point b′.

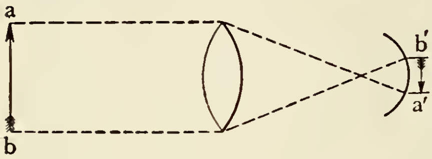


Fig. 32. Inversion of retinal image

Obviously if physical space and perceptual space are identified the problem is unanswerable. Earlier thinkers, as LeConte and Hyslop, advanced a projection theory to explain it. They assumed that the percept was reprojected out along the lines of the light rays which entered the eye and hence that by this second reversal of the image, the percept was turned right side up. The naïveté of such a theory demonstrates the confusion caused by thinking of perceptual and physical loci as identical.

But the physical image cannot be said to be " right-side-up " or " up-side-down," with reference to the perceptual object. Actually the retinal image could be in any position on the retina, and just as long as it always remained constant for a given position of the physical object it would give rise to normal perception. These terms " upness " and " downness " merely describe problems of sensori-motor coördination. They describe the orientation of the visual with reference to the somaesthetic system; that is, the constant relation between visual sensations and the sensations of position coming from the body whereby the individual is able to make a correct localizing movement in terms of them. In short they are terms belonging to perceptual space. If this is true, then it should follow that, like all other spatial features of perceptual objects, they are built up on the basis of past reactions, i.e., are learned. Then if the position of the retinal image could be reversed it should produce a reversal of the perceived object, causing it to appear " up-side-down." However, with a sufficiently long period of learning in which the sensori-motor systems were forced to coöperate according to the new relations, the " up-side-down-ness " should disappear and objects should be perceived as normally oriented with reference to the somaesthetically perceived body, or " right-side-up."

A test of this assumption was made by Stratton. He bandaged one of his eyes and devised for the other a prism lens which reversed the position of the image on the retina physically, thus producing the opposite condition to the normal. He wore this device for a period of eight days. At first objects were perceived as inverted spatially, or " up-side-down." In addition they were reversed horizontally, from right to left. The result was a loss of visual motor coördination and also of coördination between the different senses. Not only did Stratton make erroneous movements of the arm in trying to grasp objects visually perceived but he also found disagreement between the visual and auditory position of the objects.

However, there was a gradual lessening of the incoördination as the experiment progressed. At the end of eight days the readjustment had taken place and objects were visually and auditorially and tactually localized in the same place. They appeared " right-side-up." It is interesting that removal of the lens caused a new disturbance in coördination which required a period of time to overcome.

This experiment demonstrates (1) that the absolute physical position of the image on the retina does not determine how we perceive objects spatially, but that this is rather a function of the coöperation between the sensori-motor systems. (2) That visual and auditory space, for example, are not natively coincident but are built up through common localizing reactions to the same objects and therefore form a mutual perceptual-spatial system.

The experiment of Stratton was repeated and elaborated upon by Ewert, in 1930. He failed to corroborate Stratton's finding that the visually perceived objects gradually assumed an upright position. At the end of 14 days of the experiment, the "illusory disorientation effect" still remained. Ewert's controls were superior to Stratton's in various ways. He employed three subjects who wore prisms on both eyes continuously for periods of 176, 193, and 196 hours respectively; whereas Stratton experimented only on himself, with monocular vision. The fact that Ewert imposed auditory localization tests on his subjects may have disrupted the new visual motor co-ordination somewhat.

We can now take up the special problems of visual, auditory and tactual space perception.

Visual Space. The chief problems relate to the perception of depth or distance, direction, size and shape, and motion. A complicating factor is the binocular relationship, the fact that the visual fields of the two eyes overlap. A similar situation exists in audition, due to the fact of binaural hearing.

PERCEPTION OF DEPTH AND DISTANCE

If depth is not a natively given attribute of visual experiences, it must have been built up on the basis of certain cues which are supplied by visual sensation in terms of which depth is inferred. The problem of the psychologist is to determine just what these cues are. Now whenever a question of this sort is raised there is a standard method of attacking it experimentally. It is the method of creating an illusion. The logic of it is that if, by the manipulation of any given sensory factor, it is possible to produce the illusion of depth, in the absence of any real depth, then that particular sensory factor must be a cue to the perception of depth normally. Several such cues have been isolated by this procedure. For convenience they are divided into those which pertain to monocular vision, and those which result only from binocular vision.

Monocular Cues. — It is first necessary to decide what changes occur in the character of the retinal image of an object when the object is moved away from the eye in a forward direction.

Size of Image. — The size of the retinal image is a function of the size of the angle formed by the rays of light from the object at the point where they intersect in the eye. This is demonstrated in Figure 33.

The physical law can therefore be stated as follows: "The size of the retinal image is inversely proportional to the square of the distance of the visible object from the retina."

If, then, size of image operates as a cue to depth perception, the psychological law should logically be the converse of the physical law; i.e., "Other cues being held constant, the apparent distance of the object is inversely proportional to the size of the retinal image." To verify this empirically, it should be possible to produce an illusion, i.e., a change in the perceived distance of the object, by varying its actual size (and thereby varying the size of the retinal image) without altering its actual distance from the eye.

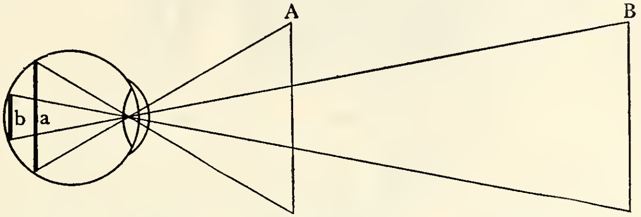


FIG. 33. Relation of size of image to distance of object

This has been experimentally verified in the following way: An apparatus (see Figure 34) is constructed in which there are two illuminated boxes, containing in front round windows whose size can be varied at will by camera shutter diaphragms. These boxes are mounted on tracks on a framework so that they can be moved forward or backward independently of one another. The experiment is performed in a dark room so that all sensory cues are eliminated with the exception of the manipulation of the size or distance of the lighted windows. The effect of size variations can then be tested in two quantitative ways, as follows: The two lights can be equated in size first and one of them can then be moved forward toward the subject a given distance, say six inches. The subject will judge the nearer light to be nearer. The other light can now be increased in size until the subject judges the two to be equidistant. The amount of increase necessary is a measure of the influence of this factor.

Another way is to make the lights unequal in size at the start, but equidistant from the subject. The subject will judge the larger to be nearer. Then the smaller light can be moved toward the subject until it is judged equally distant with the larger light. The distance it has to be advanced beyond the other light is a measure of the influence of size. In actual life situations it is necessary for the subject to be familiar with the size of the object in order to make accurate judgments of distance on the basis of size of image.

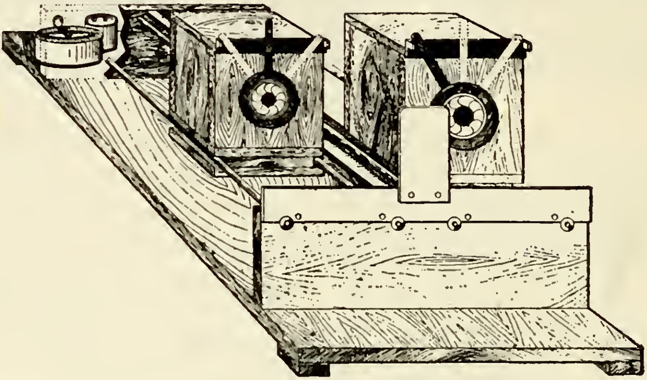


FIG. 34. Apparatus for varying intensity and size of image

Brightness of Retinal Image. — Objects when seen nearer at hand project a more intense image on the retina than when seen at a distance. The physical law for the relation between intensity and distance is: "The brightness of the image is inversely proportional to the square of the distance of the object." This is a special case of the law that the brightness of an illuminated area is inversely proportional to the square of the distance from the source of illumination.

If this differential brightness is a cue to distance perception, then it should be possible to formulate a psychological law which would be the converse of the physical law, as follows:

"Other cues being held constant, the apparent distance of the object will be inversely proportional to its brightness."

To test this, an apparatus similar to the one described is used except that the lights on the boxes are controlled by rheostats so that their relative brightnesses can be varied at will. Both lights are then adjusted to the same distance and size. One of the lights is made a certain amount brighter than the other. The subject judges it to be nearer. The weaker light is then advanced along the track until the subject judges it to be equidistant with the stronger light. This distance is a measure of the influence of the factor of brightness in distance perception.

Superposition. — If one object is in front of another in the direct line of vision that object is judged to be the nearer due to the superposition of its image over that of the other object. The effectiveness of this cue can be demonstrated in the following way:

A pseudoscope is an instrument like a pair of field glasses except that the lenses cause the images of objects to be reversed vertically and horizontally. The result is that, if two objects placed side by side are looked at, the one which is nearer looks farther away and the farther one looks nearer. But if the nearer of the two objects is placed in front of the other, so that the image is superimposed upon the other, then the illusion is at once dispelled and the nearer is seen as nearer.

Other Monocular Visual Cues. — In addition to these major cues, several others are effective and are used by artists in obtaining depth effects. Some of them are related to the ones already mentioned. Aërial perspective involves, in addition to the factor of intensity, other features which vary with distance. For example, a colored object appears desaturated and changed in hue, the outlines become blurred and details are lost. Geometrical perspective includes not only size of image but position with reference to horizon line and foreshortening of objects in the line of vision. And shading, the distribution of lights and shadows on objects, depends in part on superposition and in part on the source of light.

Accommodatory Strain. — One of the important monocular cues to depth is not, strictly speaking, a visual cue. It is, rather, a kinaesthetic cue, and consists in the strain sensations caused by the contraction of the ciliary muscle of the eye in adapting the crystalline lens for near and far vision. Figure 35 shows schematically what takes place in accommodation.

The refractive index of the lens is increased 14 diopters, in this way. As a matter of fact, the range of distance within which accommodation is effective is only about 30 feet, varying with the age of the subject. Consequently accommodatory strain is only a cue to the distance or depth of near objects. Beside the kinaesthetic strain of accommodating, there is the change in the clearness of the visual image, as it is brought into or out of focus, which furnishes a cue to its distance.

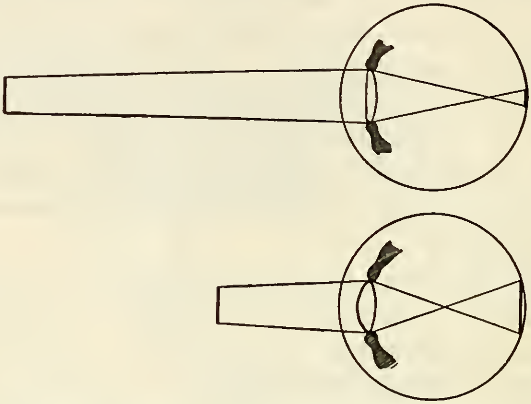


FIG. 35. Accommodation of the lens for near and far vision

In order to prove the efficacy of accommodation it is necessary to hold all other cues constant. Ordinarily convergence varies concomitantly with accommodation. But occasionally a person is discovered in whom accommodation and convergence are independently variable. One such subject, Miss Allen, was found by Carr to be able to hold convergence constant and vary accommodation at will. In these circumstances the object focused upon appeared to move back and forth. In the experiment of Swenson, to be described later in the discussion of convergence, accommodation was shown to have independent effect on judgments of depth.

All monocular cues are increased in effectiveness when both eyes are open because the effects are doubly emphasized.

Binocular Cues. — Among the most important cues in judging the distance and depth of near objects are those which result from the fact that the fields of vision of the two eyes overlap. As a result, both retinae are stimulated by the same objects. The overlapping areas include the larger half of each retina so that the greater part of the visual field is seen by both eyes simultaneously. The nose and eyebrows and cheek cut off some of the field so that a map of the overlapping field is similar to the diagram shown in Figure 36.

This is known as the cyclopean eye.

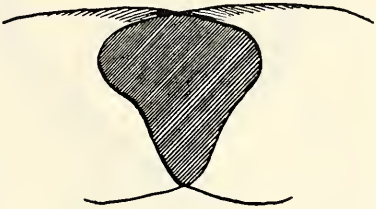


FIG. 36. Map of the cyclopean eye

The fact of double stimulation should cause objects to be seen double were it not for the principle of corresponding points. It appears that if the light-rays from a given object or point strike the two eyes in such a way that they fall on corresponding points, they give rise to single vision. Corresponding points are defined as points which would coincide if the two retinae were superimposed, one upon the other. Thus the two foveae would coincide; and for every point on the nasal hemisphere of one retina there would be a corresponding point on the temporal hemisphere of the other.

The structural and physiological basis for the principle of corresponding points is not entirely known; but certain general principles of arrangement seem to be consistent with the facts. The diagram in Figure 37 brings out these facts: Let A represent the temporal hemisphere of the left eye and let B represent the nasal hemisphere of the same eye. Then A_1 will be the nasal hemisphere of the right eye and B_1 the temporal hemisphere. According to the principle of corresponding points, all simultaneous stimulations of corresponding geometrical points on A and A_1 should give rise to single vision; whereas simultaneous stimulation of any noncorresponding points, as, for example, a point on A and a point on B_1 should give rise to double vision. To explain this it has been pointed out that the optic nerve fibers extending from retinal points a and a′ lead to the same point in the brain, due to the optic chiasma where fibers from a_1 cross over to the left side of the brain, whereas fibers from a remain on the same side. The single vision resulting is therefore attributed to the fact that the same point in the brain ultimately receives both stimulations. Fibers from a and b′, on the other hand, would not cross and hence would stimulate different regions of the brain. This explanation is pretty well supported by anatomical evidence. It is also corroborated by functional evidence from cases of hemianopsea in which blindness of one entire half of each eye results from loss of function in one occipital lobe. Corresponding points are also often defined as those retinal points which give rise to unitary vision, or those which have the same space reference. They may also be defined in terms of the supposed cause of unitary vision, i.e., those retinal points from which fibers extend to the same side of the brain.

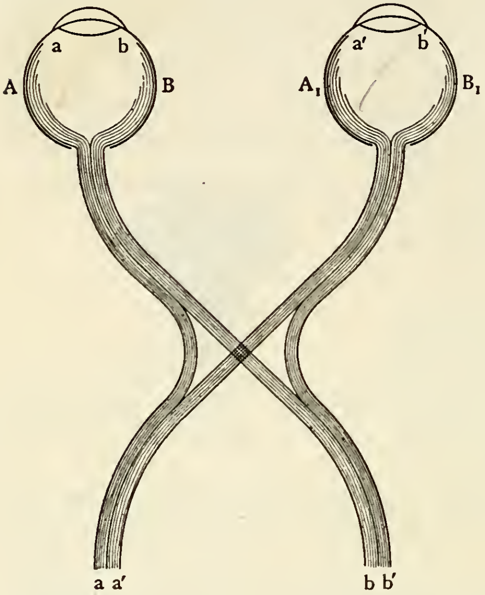


Fig. 37. The optic chiasma

The Horopter. — To know under what conditions single vision will occur, it is necessary to determine under what conditions rays of light from a single point in space will fall on corresponding points. Whenever we gaze at an object, the axes of the two eyes converge so that the lines of regard of the two eyes meet at that point in space. This is accomplished by the horizontal rotation of the two eyeballs in their sockets by the oculomotor muscles — the "interior recti." This is known as convergence. In the accompanying diagram, Figure 38, the point of regard is A. The eyes are seen to converge in such a way that the lines of regard pass through the axes of the eyes. Hence rays from A stimulate the two eyes on corresponding points, in this case the centers, a and a_1. But all points nearer or farther away than A, as B, give rise to double vision because the lines of regard passing from them through the lenses of the two eyes fall on noncorresponding points, x and y.

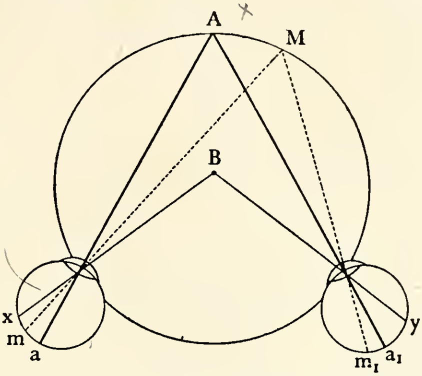


FIG. 38. The horopteric circle

The question is, are there any other points which are seen single when the eyes are focused at A. It can be demonstrated on geometrical grounds that any point on the circumference of the circle which is drawn so that it passes through A and through the nodal points of the two eyes will stimulate corresponding points. Thus the lines of regard from M strike points m and m_1 on the two retinae. This circle, just illustrated, was mapped out by Mueller, and is known as Mueller's horopteric circle. The horopter is defined as the sum of all the points that are seen single while the point of focus of the eyes remains constant. Most students, however, claim that there are other points which give rise to single vision. Some of the theories are based on mathematical and physiological grounds while others are the product of empirical experiments in visual perception. (The problem is complicated by the fact that as the eyes converge horizontally, they also twist inward on their axes slightly so that vertical lines are seen with a slight vertical slant in opposite directions by the two eyes.) Some authors hold that the horopter includes, besides Mueller's horizontal circle, a vertical line drawn through the point of focus perpendicular to the plane of vision. Others hold that these two form a curved plane all points on which are seen single; and that when the axes of the eyes are not converged but are parallel as in sleep or in looking far away, then the horopter flattens out into a plane parallel to the plane of the face and at an infinite distance therefrom.

Theoretically it should be possible to determine accurately the loci of the horopter by an empirical experiment in which the eyes are converged on a given point and a stimulus is then moved about systematically through the field of vision. But many practical obstacles stand in the way of such a test. Such points must be seen in peripheral vision which is notoriously inaccurate. Also one must attend to two things at once, in order to keep the eyes at a constant focus while exploring the excentric points.

The principle of corresponding retinal points has given rise to a split into two schools of thought — the nativist and the empirical. The former school holds that corresponding points are natively determined by the structure of the retinae and optical tracts and brain. The latter hold that the corresponding points are more functional than rigidly structural and are at least partly acquired in reacting to visual experience. Some evidence has been contributed to the controversy by clinical cases. For example, if a cross-eyed person has been strabismic from birth, then he has never experienced the kind of single vision resulting from the stimulation of geometrically corresponding points. Do such persons have single vision? And, when operated on, do they immediately have single vision or is this gradually or ever attained? The evidence shows that strabismus is compensated for in different ways. Usually one or the other eye is dominant and stimulations of the other eye are ignored. A few rare cases seem to show the establishment of a new functional system of corresponding points. But the evidence is not crucial. Some subjects alternate between complete dominance of one or the other eye. When an operation removes the strabismus, normal sight is usually achieved rapidly, showing that the unused eye has not atrophied and that presumably there is a native basis for the rapid adaptation which occurs.

The other line of evidence has to do with certain rare cases of hemianopsia reported by Goldstein in which a region around the fovea of one eye was blind. These subjects were reported to have established a new functional fovea, or pseudofovea, located excentrically in the middle of the unaffected half of the retina. This, of course, would require the acquisition of a new functional system of corresponding points, if normal vision was to be attained. The evidence is still not crucial for such important implications as this would have.

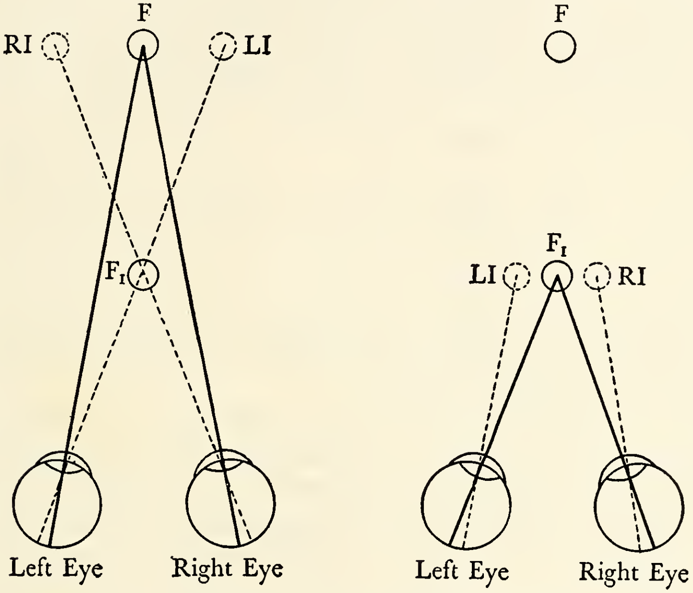


FIG. 39. Crossed and uncrossed finger images

Crossed and Uncrossed Images. — In describing the horopter, we pointed out that objects lying at the intersection of the lines of regard are seen as single, while objects lying behind or in front of this point of intersection are seen as double. The doubling which results, however, is of two sorts, depending on whether the object lies on the farther or nearer side of the point of intersection. This can be shown by a diagram of a simple demonstration with the fingers. If the index fingers of the two hands are held directly in front of the face in the median plane, one in front of the other, then if the near one is looked at, the far one is doubled and vice versa. But it is possible, by alternately shutting one eye and then the other, to discover that when the farther finger is focused upon, the nearer one is doubled in such a way that the images are crossed; i.e., the left eye sees the finger image on the right side and the right eye sees the finger image on the left side. If however the nearer finger is focused upon, the farther one is doubled in such a way that the images are uncrossed; i.e., the left eye sees the image on the left side and the right eye sees the image on the right side. This becomes an important cue to depth perception because the individual learns to interpret crossed images to mean that the object is nearer than the point of focus and uncrossed images to mean that it is farther away. Refer to Figure 39. Let F equal the farther finger and F_1 the nearer. Then in Fig. I, where the eyes are converged on F the right and left images (R.I. and L.I.) will appear in the crossed positions shown. Whereas in Fig. II, where the eyes are converged on F_1, the images will appear in the uncrossed positions (L.I. and R.I.) shown.

Objects Lying on the Lines of Regard. — A further fact should be mentioned in connection with double images because of its bearing on stereoscopy. We have described the conditions under which a single object is seen as single. But nothing has been said about the conditions under which two objects will be combined and seen as one. In Fig. I above, the object F is seen as single because the light rays from it fall on corresponding points. Now it is clear that if two objects were placed so that each lay on one of the lines of regard, somewhere between the point of intersection and the eyes, these two objects would stimulate the same corresponding points that were stimulated by the one object located at the point of intersection. Hence the two objects would be seen as one.

The Binocular Parallax. — If, as has been explained, objects lying outside the plane of the point of focus of the eyes give rise to double images, this fact is important for depth perception. For the *degree* of doubling is proportional to the distance of the object from the focal point. Hence, conversely, the distance of the object from the focal point can be judged by the distance apart of the double images.

In addition, it is evident that when a solid object is looked at, the two eyes receive different views of it. The left eye sees farther around on the left side of the object, and the right eye sees more of the right side. The degree of discrepancy between the two views is proportional to the depth of the object. This discrepancy of images in viewing solid objects is called the " binocular parallax " and is caused by the separation of the two eyes from one another. The question is, how important a cue is the binocular parallax to the perception of depth or solidity? This can be answered by a simple experiment.

Stereoscopy. — If the disparateness of the images, or binocular parallax, is a cue to depth, then it ought to be possible to produce the illusion of depth by presenting the two eyes with disparate images, even though they lack real depth. Now, if two photographs of an object are taken from points at the same distance apart as the eyes, the photographs should have the same amount of disparateness as the retinal images would have in actual vision. The photographs could be said to illustrate the binocular parallax. And if these photos should be exposed to the eyes in such a way that they would fuse into a single percept, the resulting percept should give the illusion of depth.

That this is actually the case can be shown with a stereoscope. This instrument, invented by Brewster, presents the two photographs to the eyes in such a way that they fall on the respective lines of regard. We have pointed out that when two objects fall on the lines of regard, they stimulate corresponding points and are seen as a single object. Hence the two photographs are seen as one, but with the binocular parallax. The result is to give the fused photograph an apparent depth which is very striking. Moreover, by widening the distance apart at which the photographs of the object were taken, it is possible to exaggerate the parallax, and thus exaggerate the apparent depth in the fused picture. Conversely, if the two photographs are identical, no depth effect will occur. This proves that the binocular parallax in ordinary vision is an effective cue.

Several forms of stereoscopy are possible.

Free stereoscopy. — If two identical flat pictures of small size be placed before the eyes at about the interocular distance apart and then if the gaze be directed straight ahead between the pictures, at a distant point, the pictures will fuse into one. Now if the pictures are not identical but are disparate in accordance with the binocular parallax, they will not only fuse but will give the illusion of depth or third dimension.

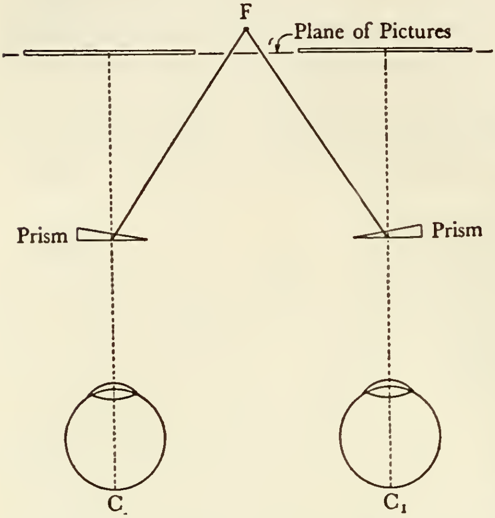


FIG. 40. Effect of stereoscope on light rays

The difficulty with this procedure is that, since the eyes are converged beyond the pictures, they are also accommodated to the greater distance (for accommodation and convergence are ordinarily incapable of independent functioning). Therefore the images are blurred. To rectify this the following instrumental method has been devised:

The Stereoscope. — Although the first stereoscope invented was the reflecting stereoscope of Wheatstone, a more serviceable instrument was devised by Brewster about 1843. The essential feature of this instrument is that it places refracting prisms before the eyes which bend the light rays from the two pictures so that the observer can both converge and accommodate at the same distance, i.e., at the plane of the pictures. This causes the images to come into clear focus. Figure 40 illustrate this.

The pictures are seen as a single fused image at F, because of the bending of the light rays by the prisms, so that they fall on the corresponding points of the retinae, c and c_1. The additional features of the Brewster stereoscope are, first that the eyes are hooded to exclude all light except that transmitted through the lenses, and second that a partition between the prisms allows each eye to see only the picture on its side.

Still another type of stereoscopy is that produced by mirrors, as shown in the diagram, in Figure 41. The apparatus consists of four mirrors, a, b, c, and d, mounted on a bar, m–n, in the positions indicated. Then if the pictures, P and P_1, photographed from slightly different angles, are placed in the positions shown, the rays will be reflected from them to the mirrors c and d, thence to a and b, and thence to the eyes. The resulting fused image will be seen at F, behind the plane of the central mirrors.

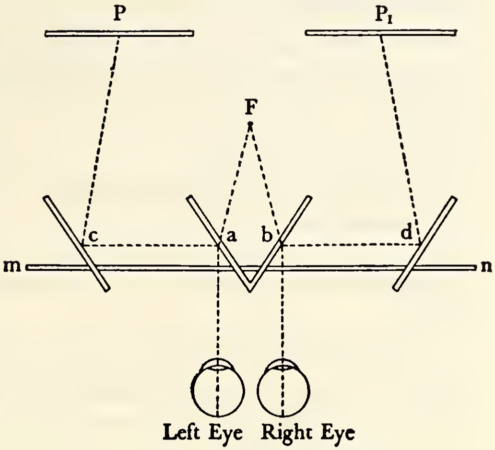


FIG. 41. The mirror stereoscope

This same apparatus can be used to exaggerate the depth effect from normal vision in the following way: Since the binocular parallax is a function of the interocular distance it can be exaggerated by increasing the interocular distance. This cannot actually be done, but the same effect results when mirrors c and d are trained upon a real object and are moved out along bar m–n until the distance between them is greatly increased. The two images of the real object then fuse into a single image having an exaggerated appearance of depth. See Figure 42,

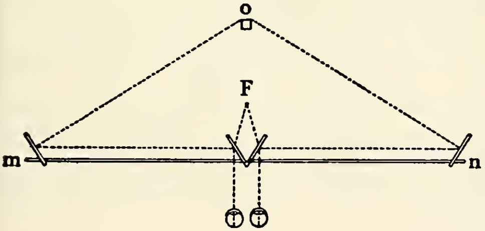


FIG. 42. The telestereoscope

where o is the real object and the other parts are adjusted accordingly. This is called a telestereoscope or teleroscope because, by means of it, depth effect can be given to very distant objects.

Stereoscopic Proof of the Efficacy of the Binocular Cues.— Incidentally we have mentioned all the major binocular cues to depth. They are:

Binocular parallax
Crossed and uncrossed images
Convergence

Experimental proofs of all of these can be given by stereoscopy.

(1) The effect of binocular parallax can be shown in several ways. (a) If a stereogram containing identical pictures is looked at through a stereoscope, practically no depth effect results; but if the stereogram contains disparate photographs, depth effect is observed. (b) When a stereogram, which gives depth effect viewed stereoscopically, is looked at in direct vision, most of the depth effect disappears. (c) Stereograms which contain photos taken from points farther apart than the interocular distance, give exaggerated depth effect because the binocular parallax is exaggerated.

(2) The effect of crossed versus uncrossed images can be demonstrated effectively with a stereogram of the moon viewed through an ordinary stereoscope. If the right and left stereograms are in their correct positions, the moon appears to be convex; but if they are reversed so that the left image is exposed to the right eye and the right image to the left eye, then the moon appears concave. This can also be accomplished by a special stereoscope which exposes the left eye to the right image and vice versa. It can likewise be demonstrated by a pseudoscope which inverts the images from left to right by means of lenses.

(3) The effect of convergence is difficult to demonstrate because it is necessary to eliminate the factor of accommodation which varies concomitantly with it. Also it is necessary to eliminate the factor of binocular parallax. Both of these factors can be controlled and the role of convergence demon-

strated by a telestereoscope. Judd devised the following experiment:

Since accommodation is only efficacious at near distances, an object at any distance beyond a hundred feet would not be affected by it. The same is true of the parallax. Therefore neither of these cues could be effective in viewing a distant object like a star. Factors like size and intensity of image would also be held constant. But if a star be viewed through a telestereoscope it is possible to alter the convergence of the eyes either by moving the mirrors farther away from each other or by rotating either pair on their axes so that they reflect at a different angle. When this is done the star appears to jump toward or away from the observer and the effect is proportional to the amount of change in convergence.

There are other ways of demonstrating the efficacy of convergence, but they fail to divorce it from accommodation.

(a) The negative after-image method. If a negative after-image is obtained and the eyes are then closed it is possible to vary the apparent size and distance of the after-image by converging or diverging the closed eyes.

(b) If an isolated point of light is moved slightly forward or backward in a dark room, the movement can be detected. Since all other cues are eliminated by darkness, except intensity and size changes which are negligible, the judgment must be based on strain of convergence and accommodation. Similar results can be produced with a white thread suspended in a dark box into which the subject looks, through an aperture.

(c) If we suddenly shift from monocular to binocular vision objects appear to jump forward. It can also be noticed that distances of flat objects are judged better in binocular vision. Such objects do not yield disparate images. This method of proof was used by Wundt, Hillebrand, Baird, and others. The defect with the method is that it assumes that convergence does not operate in monocular vision, whereas the closed eyes can converge.

(d) Voluntary dissociation of accommodation and convergence is possible for a few persons. Carr tested a subject, Miss Allen, who from childhood had been able to shift accommodation while holding convergence constant. Objects appeared to jump forward or backward when this occurred. An experiment was performed in which convergence was controlled by having the subject gaze at two bright wires placed vertically before the eyes, their distance apart being adjustable at will. The subject was directed to combine the wires stereoscopically into a single image. That convergence was held constant in this way is shown by the fact that no doubling occurred, and no convergent movements of the eyeballs could be detected, even with an ophthalmoscope. Yet Miss Allen could voluntarily make the image of the wires jump back and forth. That this was due to accommodatory changes was proved by the concomitant changes in apparent clearness and size of the image reported, by the changes in size of pupil which are reflex accompaniments of lenticular adjustments, and by actual lenticular changes observed with a phakoscope. When convergence was systematically varied by moving the wires apart, with accommodation held constant, no apparent distance changes occurred. This shows that in the case of this subject convergence was not a distance cue. But other subjects have been reported, for example Hyslop, in whom convergence was a cue and accommodation not, so it is evident that great individual differences occur in the importance of the two factors. The dissociation is not always voluntary as it was in Miss Allen's case.

Recently a quantitative study of the relative influence of the two factors of accommodation and convergence in depth perception was made by Swenson. His apparatus was a modified form of the mirror stereoscope, which permitted the alteration of either convergence or accommodation while keeping the other constant, and without introducing any concomitant changes of any of the secondary criteria. Two telescopic tubes with translucent milk-glass screens at the ends, lighted from behind, were mounted on a frame in such a way that they could be rotated about centers which coincided with the centers of rotation of the eyes. The tubes were bent near the fixation ends at an angle of 88 degrees with mirrors placed at the angles in such a way that the lighted glass screens were seen as a single circular light, straight ahead of the eyes. Convergence could be manipulated by rotating the tubes, without altering the actual distance of the circular light. Accommodatory changes could be induced by shortening or lengthening the tubes, thus bringing the circular lights nearer to or farther from the eyes. The size of the circular lights was varied by a camera-like diaphragm concomitantly with changes in distance, and brightness was kept constant by the changes in size of the lighted openings. In order to secure quantitative judgments of the apparent change in location of the fused image (the circular light) with convergent and accommodatory changes, a graduated rod was placed so as to project straight back from the eyes along the line of regard. A movable pointer was mounted on the rod so that the subject could move it back or forth to the point where the visible object (the circular light) appeared to be located. Three different positions of convergence and three of accommodation were tried and it was found that both accommodation and convergence were effective, but the latter was about three times as effective as the former. And when the two were widely dissociated, for example if accommodation was set at 25 and convergence at 40 c.m., then the subjects tended to ignore the former and use only the latter in judging.

Anaglyphic Stereoscopy. — A method of stereoscopy which is sometimes used, and which gives effects similar to those of other methods, is anaglyphic stereoscopy. The stereograms are prepared by superimposing one photograph on the other but printing one in red and the other in green. The photos are of course taken from disparate points of view. The subject looks through glasses which have a red lens for one eye and a green lens for the other. As a result, the left eye sees only the image intended for it and the right eye sees only its image. But the combined effect is a fused image with the depth effect due to the binocular parallax.

A phenomenon of colored vision not to be confused with the above is the tendency for certain colors to appear nearer than others. Thus red appears nearer than blue, etc. It is called color stereoscopy. The explanation of the phenomenon is quite complicated, involving the principle of chromatic aberration, the excentric position of the pupil with relation to the optical axis, etc. Suffice it to say that it is a phenomenon which occurs with binocular and not monocular vision.

REFERENCES

Baird, J. W. The influence of accommodation and convergence upon the perception of depth. *Am. J. Psychol.*, 1903, 14, 150–200.

Carr, H. A., & Allen, J. B. A study of certain relations of accommodation and convergence to the judgment of the third dimension. *Psychol. Rev.*, 1906, 13, 258–275.

Ewert, P. H. A study of the effect of inverted retinal stimulation upon spatially co-ordinated behavior. *Genet. Psychol. Monog.*, 1930, 7, 177–363.

Gelb, A., & Goldstein, K. Psychologische Analysen hirnpathologischer Falle. Leipzig, 1920. Zur Frage nach der gegenseitigen funktionellen Beziehung der geschadigten und der ungeschadigten Lebsphare bei Hemianopsie. *Psychol. Forschung,* 1925, 6, 187–199.

Hillebrand, F. Das Verhaltniss von Accommodation und Convergenz zur Tiefenlokalization. *Zeitschrift fur Psych. u. Physiol. der Sinnesorg,* 1894, 7, 97–151.

Hyslop, J. H. Experiments in space perception. *Psychol. Rev.*, 1894, 1, 257–73; 581–601.

Hyslop, J. H. Upright vision. *Psychol. Rev.*, 1897, 4, 142–163.

Judd, C. H. Some facts of binocular vision. *Psychol. Rev.*, 1897, 4, 371–389.

LeConte, J. Sight, an exposition of the principles of monocular and binocular vision. London: Kegan Paul, 1895.

Latta, R. Notes on a case of successful operation for congenital cataract in an adult. *Brit. J. Psychol.*, 1905, 1, 135–151.

Miner, B. A case of vision acquired in adult life. *Psychol. Rev., Monog. Suppl.*, 1905, 6, No. 28, 103–118.

Stevens, H. C. Peculiarities of peripheral vision. *Psychol. Rev.*, 1908, 15, 69–93.

Stratton, G. M. Vision without inversion of the retinal image. *Psychol. Rev.*, 1897, 4, 341–463.

Swenson, H. A. The relative influence of accommodation and convergence in the judgment of distance. *J. Gen. Psychol.*, 1932, 7, 360–380.

Wundt, W. Beitrage zur Theorie der Sinneswahrnehmung. Leipzig, 1862.

CHAPTER VII

VISUAL SPACE: SIZE, SHAPE, AND MOTION

PERCEPTION OF SIZE. — Whereas distance and depth perception have to do with stimulations in the third dimension, size is concerned with stimulations in the plane parallel to the face; though of course variations in distance affect the size of the retinal image.

The nativistic and empirical viewpoints are both represented here also. Some theorists tend to emphasize structure of retina and refractive conditions as causes of illusions of size, while others stress acquired factors, habit, compensation, aesthetic motives, motor strains, and the like.

On the structural side it is a fact that the size of the image is a function of the position where the retinal stimulation occurs. First there are disparities between the different meridians. Second, the periphery gives different effects from the fovea. The latter case was studied by Stevens. He found the following facts: —

(a) Objects in the right hand visual field tend to appear larger than those in the left. But with left-handed individuals, objects in the left field appear larger.

(b) Objects in the upper field appear larger than in the lower.

(c) Objects seen in peripheral vision appear larger than those seen foveally; the effect is exaggerated as the distance from the fovea increases. These results are shown in Figure 43. It is a diagram of the relative size of a white disc as it appeared on different regions of the retina.

This discrepancy between fovea and periphery probably has a twofold basis. It is partly due to the lower sensitivity of the peripheral retina, and partly to refractive factors, chiefly spherical aberration.

Another phenomenon of peripheral vision can be demonstrated by viewing, at close range, a card containing parallel rows of horizontal and vertical lines crossing. The lines will appear convex.

And if a card be prepared in which the lines are drawn with the reverse flexions, it will be found that they appear parallel when looked at from close range, as in Figure 44. The reason is that the outer lines are seen excentrically. The effect is that of a system of spherical coordinates projected onto a plane.

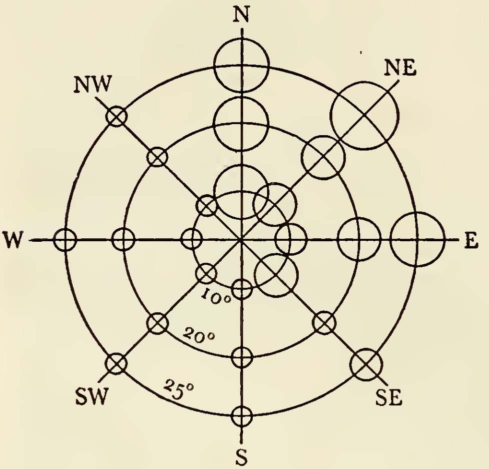


Fig. 43. Apparent size of a white disc as seen from different parts of the retina

After Stevens in *Psychol. Review,* 1908, 15, p. 75, Fig. 2

There are certain special illusions involving distortions of size which are partly explained by the foregoing factors but for which other theories have also been advanced. Among these are the vertical-horizontal illusion, the Müller-Lyer illusion, and the illusion of filled space or interrupted extent.

The Vertical-Horizontal Illusion

The vertical-horizontal illusion is the tendency for vertical lines to appear longer than horizontal lines. On the structural side we have the fact that the horizontal meridian is longer than the vertical. It is therefore agreed that, since a vertical line of given length stimulates a larger percentage of the total vertical meridian than the percentage of the horizontal meridian that would be stimulated by an equally long horizontal line, the vertical line is judged longer. It is also possible that the illusion is a special case of the peripheral size exaggeration studied by Stevens.

The Müller-Lyer Illusion

The Müller-Lyer illusion shown in Figure 45, in which the lower line appears longer than the upper, has been variously explained. One theory originating with Wundt was that the lengthened appearance of the lower line was caused by expansive movements or motor tendencies of the oculomotor muscles causing the eyes to move outward, whereas the auxiliary lines in the upper line induced contracting or converging movements of the eyes. But the eye movements of subjects were carefully photographed while they gazed at the Müller-Lyer figure by Judd, with negative results. That is, although he found a consistent tendency on the part of his five subjects to show restricted movements in looking across the underestimated Müller-Lyer figure, and a freer movement in looking across the overestimated figure, yet there is evidence from other illusions, as the filled-unfilled space illusion, that a series of restricted movements may lead to overestimation, and free movement to underestimation. And there is no certainty that any movement at all would have occurred if the subject had been allowed merely to gaze at the figure without being told to move his eyes across it. Continued practice with the illusion, in the case of one subject, caused considerable change in the nature of the eye movements, but not of such a nature as to confirm the move-

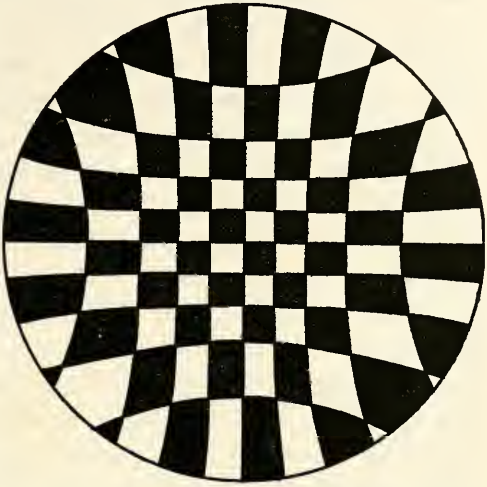


FIG. 44. Distortion of lines in peripheral vision

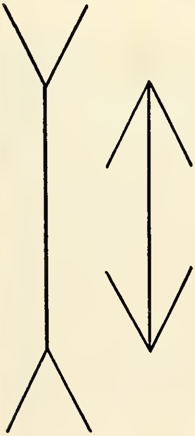


FIG. 45. Müller-Lyer illusion

ment sensation theory. A brief description of the apparatus used in these eye movement studies is in order.

Dodge and Stratton employed a slightly different method from that used by Judd but the principle is the same. The essential feature is to photograph, by means of a motion film, the movements of the eye. This is done in one of two ways: either to project a beam of light on the cornea of the eye and then to photograph the movements of this eye or speck of light, or to attach a small spot of white material, as Chinese white, to the cornea and to photograph its movements in the same way. The latter method was used by Judd, but in modern experiments in eye movements the Dodge method prevails. Its only defect is that the point of light caused by the beam projected on the cornea does not move proportionally to the movement of the eyeball, but its movements are foreshortened. Since a moving picture film moves only in one direction, it is necessary to use two simultaneously moving films traveling in directions perpendicular to each other so that both horizontal and vertical eye movements can be recorded.

The Filled-Unfilled Space Illusion

The filled-unfilled space illusion is that in which a space filled with solid objects or broken up into smaller lengths appears longer than an equal space which is empty. This illusion has also been ascribed to eye movements, but as pointed out, it leads to contradictions with the findings for other illusions. In addition to the theories mentioned, there are those of contrast and confluence which look for an explanation in terms of the contrasting effect of lines and areas and directions. The Gestalt School of Psychology has utilized all of the size and shape illusions of visual perception in supporting the configurational theory and this point of view will be explained later.

PERCEPTION OF SHAPE

LIKE size perception, the perception of shape can be shown to be a function of both native and empirical factors. On the native side, shape is determined, in part, by the shape of the retinal image. It is also a function of the particular region of the retina which is stimulated. In addition, the shape changes with the plane of projection. For example, if an afterimage is obtained of a cross formed by lines at right angles, this can be variously distorted by being projected against planes at various angles to the plane of the face.

On the empirical side the shape of objects can be shown to be in part a function of movements, in accordance with the motor theory of shape perception, and, in part, a function of the influence which surrounding objects exert upon the object in question. The latter principle is demonstrated in the case of the Poggendorff illusion, in which an oblique line appears distorted by vertical lines drawn across it, and the Zöllner illusion, in which two parallel lines appear to bulge away from or toward each other as a result of a series of lines drawn at angles to them. A discussion of the Gestalt interpretation of illusions of shape will be postponed.

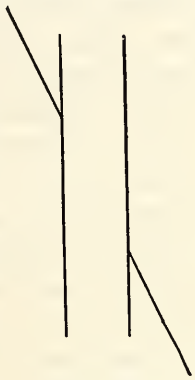


FIG. 46. Poggendorff illusion

PERCEPTION OF DIRECTION

THE manner in which we perceive the location of objects in a plane parallel to the face, i.e., whether to the right or left or above or below, is a complicated process. But specific cues can be studied separately. The more important will be suggested.

Local Sign. — If the eye and head and body are held stationary, then the part of the retina which is stimulated by a given visible object is determined by the direction of the object from the eye. Hence for every position in space (in a plane parallel with the face) there is a corresponding unique point of stimulation on the retina. Now if we assume that each different retinal point stimulated gives rise to a different sensory experience, it can be understood that every position in space, relative to the retina, would have its own local sign. However the actual association of these discrete sensory signs or experiences with definite positions in perceptual space is no doubt an acquired ability. When an object lies to the left of our visual field, it natively gives rise to a particular experience. But to connect that particular experience (local sign), with the orientation of that object in our perceptual space necessitates reacting many times to the object by reaching for it or moving toward it, until a sensory motor coördination has been established by trial and error. Thereafter the local sign is a sufficient cue to direction. Response to local signs is so immediate and habitual as hardly to involve conscious attention. Yet, that it is learned by reacting is proved by Stratton's experiment, previously described.

Eye Movements. — There is a tendency, probably native, to turn the eye toward the point in space from which a retinal stimulation is being received, so that the stimulation falls on the fovea or center of vision. If the stimulus-object lies to the left, the eye is moved to the left. Such eye movement gives rise to kinaesthetic sensations of a characteristic sort. In this way an association is formed between the spatial direction of the stimulus object and the particular kind of kinaesthetic sensation experienced in ocularly adjusting to it. This establishes a cue to direction.

Relation of Eye, Head, and Body. — In the last analysis, *direction* means direction relative to our own body. If local retinal sign is a cue to the direction of the stimulus relative to the eye, how do we perceive its direction relative to the body? It is necessary to know the position of the eye's axis relative to the body. This is determined through cutaneous, kinaesthetic and visual cues. The body is seen in indirect vision. The position of the eye in the head is felt cutaneously as is the position of the head relative to the trunk.

The Localizing Reaction. — A final factor of importance is the motor act, usually of the hand, of reacting overtly to the stimulus-object. When, by trial and error, the stimulus-object is successfully reached for and grasped, its position relative to the body has been established by the visual and kinaesthetic awareness of the hand's movements. If any of these cues are eliminated, location is less accurate. This is shown by an experiment of Carr and Loemker. The apparatus consisted of a curved metal backplate on which was placed the article to be localized. A horizontal shelf extended forward from this so that the subject could not see his hand and forearm which operated beneath the shelf. His task was to place a pointer directly below where he saw the object. A black cloth screen made it possible further to conceal from the subject the position of his whole arm and shoulder in reacting. Finally, an eye piece was worn, consisting of two short tubes in the end of which were small slits, one-eighth inch wide, for the subject to look through. These slits could be moved to left or right so that the subject would have to look out of them at an angle by turning the head. Not only did the removal of the visual sight of the reacting arm and hand cause false localizations, but any distortion of the axis of the eyes relative to the plane of the body caused a constant error.

PERCEPTION OF MOTION

Since visual perception depends on the stimulation of specific points on the retina, the question arises as to how we perceive motion. It is possible to detect the position of an object at any given time, as has been shown by the particular local signs of the retinal points stimulated by the object, but how is it possible to perceive changes in the position of an object? Motion involves a combination of space and time sense. Motion is, then, merely the occupation of different successive positions in space at successive periods of time. It is possible to infer that an object has moved by the fact that it stimulates a different retinal point, but how is it possible to perceive the motion while it is taking place? Do we actually see motion as a visual or visual kinaesthetic experience, or is it an inference? The answer to this problem is complicated by the fact that motion is perceived in several different ways, depending upon the particular conditions involved. For example, it is possible to perceive motion when the eyes are stationary with reference to the visual field, and some particular object in the field is moving across it. Again the visual field may be stationary, but the object may be moving and the eyes following it. In this case it would be the same as if the visual field were moving in the opposite direction and the objects were stationary with reference to the retina. A third case would be that in which the eyes are stationary in the head but the head is moving with the moving object. The effect in this case would be identical with that in the preceding. Other complications are offered by those situations in which the whole body is moving even though the eyes and head are stationary with reference to the body, as in the case of standing on a revolving platform, or standing on the back platform of a fast moving train. In one case the visual field is moving past the retina, and in the other case the visual field is rapidly receding into the distance. In all of these situations the perceptual process is complicated by cues from other than visual sense organs. For example, in the case of the revolving platform the equilibratory sense is brought into play as well as incipient corrective movements of the eyes, and various kinaesthetic and visual sensations are added. Especially is this true in the case of riding up or down in an elevator, where the chief cue is the momentum and inertia of the visceral organs.

To return to the first situation in which the retina is stationary with reference to the visual field but the object is moving across the visual field and therefore across the retina. This is the typical situation and the one which has given rise to the most fruitful and far-reaching experiments. As a stimulus-object moves across the visual field, it stimulates successive points along the retina at successive intervals of time. These successive stimulations may be very rapid or very slow. If rapid, it is doubtful whether the successive points receive sufficient stimulation to give more than an impression of a vague streak, which would be caused by the fading afterimages of stimulation. If a burning brand is waved about at night such an afterimage streak is observed, but since the retinal elements are separated by a finite distance, we must assume that the moving object would stimulate a finite number of points along the retina. Hence, the motion perceived would consist in successive temporal stimulations of spatially disparate points. If this assumption is correct, then it would be possible to produce an illusion of motion by successively stimulating spatially disparate points along the retina at rapid intervals, by stationary stimuli.

The Cinema Illusion. — This illusion can be demonstrated experimentally and illustrates the same principle which has given rise to the motion picture or cinema. The motion picture is produced by the stimulation at rapid intervals of successive points on the retina, by stationary pictures. Since these pictures were taken of moving objects at successive intervals of time, they are progressively disparate and, hence, give rise to stimulation of disparate points. The result is the apparent movement of the objects in the picture. The illusion has also been utilized in the production of apparent motion in illuminated advertisements. If a row of lights be successively flashed on at rapid intervals, it will give rise to the illusion of a single light moving across the field of vision.

How far apart can two stimulations occur in time and space and still give rise to perception of motion? The answer has been worked out by Korte and is embodied in the Korte Laws. Briefly these laws are as follows: The variables involved are the intensity of the stimulations, the distance apart of the stimulations, the time interval between the stimulations, and the time that the retina is exposed to the stimulus which will be called exposure time. Korte points out that some of these factors are integrative; i.e., they tend to facilitate the perception of motion, and some are disintegrative; i.e., they tend to disrupt the illusion of motion. A proper balance must be achieved between the various factors in order to secure an optimal illusion of motion. The greater the intensity, the smaller the exposure time but the shorter the interval necessary. The greater the distance between stimulations, the longer the time interval necessary. A related phenomenon is the flicker phenomenon, in which a disc composed of equal areas of black and white is rapidly revolved. At low rates of speed the revolving disc gives rise to a sensation of flicker but an optimal point can be reached at which flicker ceases and a homogeneous surface is presented.

What is the effect, on the perception of relative motion, of such factors as the relative size and intensity of the moving objects, the direction of fixation, and the direction and speed with which they move? This can best be determined by manipulating two lights in a darkened room. A series of studies has been made, one of which was reported by Carr and Hardy, another by Thelin. The former investigators, by holding one light stationary and moving the other, found that their subjects judged most accurately when the lights differed from one another, either in size or in brightness, or when the moving light was moved rapidly, or when the subjects looked at the stationary light directly. Thelin, however, demonstrated that inequality of intensity decreased accuracy of judgment when both lights were moving; while, with one light stationary, accuracy was increased or decreased depending on which light (the brighter or the dimmer) was fixated and which was moving.

The Stratton Swimming Illusion. — There are certain special illusions of motion which have been noted by experimenters in visual phenomena. One of these is the Stratton swimming illusion. Stratton noticed that when he first wore the lenses which reversed the image not only vertically but also horizontally, from left to right, the entire field of vision appeared to move or swim in the opposite direction from that in which he moved his eyes and head. In ordinary vision this effect does not occur, even though the stimulations from the visual field actually do arouse disparate points on the retina at successive intervals, and hence fulfill the requirements for perceiving motion. The explanation in the case of normal vision is apparently that the individual has learned to ignore or compensate for this swimming effect. This adjustment, however, fails to meet the novel situation produced by the Stratton lenses. This can be illustrated by the diagram, in Figure 47. It will be seen that in normal vision the visual background would move in the opposite direction from that in which the eye is turned; whereas, in the special case of the Stratton lenses the apparent movement would be in the same direction as that of the eyes.

The Whiplash Illusion. — Another special illusion is called the " whiplash " illusion. This is as follows: if a pendulum with an illuminated weight swings rapidly, the distance of the swing seems to be greater than it actually is; i.e., the weight appears to move beyond the point at which it actually stops at the end of each swing. This effect is greatly exaggerated when the point of fixation is above the moving light so that the light is perceived peripherally. Dodge used this illusion to refute the eye movement theory of apparent motion in the following way: Two lights of weak intensity were placed on the two arms of a counterbalanced pendulum. One of these swinging lights was fixated by the eye thus causing the other to be perceived in peripheral vision. Since it was photographically demonstrated that during the last part of the swing the image of the fixated light remains stationary on the retina, Dodge held that the fixated light should appear motionless during the last part of the swing. The peripherally perceived light, on the other hand, should appear to move after the fixated light had stopped, thus giving the whiplash effect, which actually occurred. This was interpreted by Dodge to mean that motion is only perceived through retinal displacement and not through eye movement. But the phenomenon is obviously capable of interpretation in other ways. Carr repeated the experiment, and found that the fixated light was perceived in motion during that period when, according to Dodge, it should appear motionless. This corroborates the eye-movement theory.

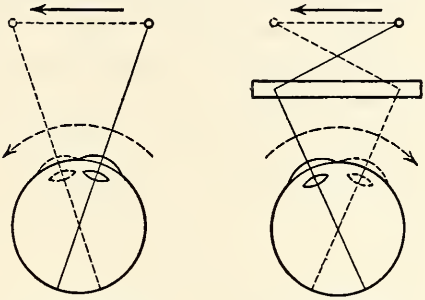

A. Normal Eye Movement
B. Swimming Effect

FIG. 47. Stratton swimming illusion

The Autokinetic Phenomenon.—Another related illusion of motion is known as the autokinetic phenomenon. If a stationary point of light is perceived in a darkened room, the light will appear to move about or make small excursions in space. Usually these movements do not appear at once but gradually increase in size the longer the light is fixated. The nature of the motion differs with individuals. With some it is a backward and forward swing; with others complete circular motions and sometimes vertical excursions. Since the light is fixated there is no displacement of the image on the retina. Careful photographic tests show that no eye movements take place. The phenomenon is seen monocularly as well as binocularly. There is some evidence that it can be exaggerated or to some extent determined as to direction and amount by previous movements of the eyes before fixating the light. It is therefore thought to be a product of strain sensations resulting from previous contractions of the oculo-motor muscles rather than from eye movements occurring at the time of fixation. Carr finds four factors effective: the position of the eye in the socket; the after-effects of such position; the motor strains produced by attempt at voluntary control of the illusion; and the after-effects of such strains.

The Afterimage of Movement.—Still another illusion of motion probably related to the preceding is called the after-image of movement. When a continuously flowing movement is observed for some time, and then the gaze is fixated upon a stationary object, this object will appear to move in the opposite direction. Some instances are the following: (1) If an individual stands on a bridge and looks down at a rapidly flowing current of water, and then suddenly turns and gazes at the bank, it will appear to move in the opposite direction; (2) When a person observes a landscape from the window of a moving train for some time, if the train suddenly stops, the landscape will appear to flow in the direction in which the train was moving; (3) If a black spiral coil be drawn on a white disc so that the black line spreads out from the center of the disc in ever-widening concentric circles, an illusion of motion can be obtained in the following way: The disc is revolved on a color wheel at an optimal rate. The subject gazes at the disc for about 10 seconds and then turns and looks at some stationary object. The object will appear to move in the opposite direction from that of the spiral; i.e., if the spiral was revolved clockwise so that its apparent motion was outward, the object will appear to shrink in size. Under the reverse conditions, it will appear to swell. Along with the swelling or shrinking objects appear to move forward or backward in space. A special form of this illusion is produced by revolving a cylinder on which circular black lines have been drawn. Hunter made a special study of the illusion in this form.

All of these illusions are similar in that they involve aftereffects of perceived movement rather than effects occurring simultaneously with the stimulation. Earlier explanations such as those given by Purkinje, Lotze, Helmholz, Wundt and others were stated in terms of compensatory eye movements, but it has been demonstrated that eye movements do not occur, and in the case of the spiral illusion, it would be impossible for eye movements to account for the effect, as the object seems to swell out in every direction from a center. Consequently, we are compelled to explain it either in terms of central factors of a non-peripheral character, or else to assume some sort of disturbance of the retinal elements by the original stimulation, resulting in a compensatory readjustment of these elements. Hunter came to the conclusion that at least 3 factors were operative: (1) Afterimages; (2) Associational factors; and (3) Kinaesthetic sensations resulting from oculo-motor strains. Wolgemuth on the other hand postulated some process of cortical drainage in addition to the factor of successive induction in the retina.

Gestalt Interpretations

All of these phenomena of perception of movement, real and illusory, as well as the special illusions of size and shape, have been studied by Gestalt psychologists, notably Wertheimer, Koffka, and Köhler, and have been interpreted by them in terms of a unique theory which will now be briefly set forth. To begin with, the Gestalt school repudiates all theories which assume a one-to-one relationship between stimulus elements and perceptual elements. Such a hypothesis, namely, that each stimulus determines its sensation in the same way whether alone or in constellation with others, is called by Köhler the Constancy Hypothesis. In opposition to this they assume that the individual responds to stimulus configurations as wholes; that there are principles governing the manner of responding to these wholes or Gestalts which do not apply to the parts alone, but result from their togetherness. The neural physiology of perception in the Gestalt system is not clear but an attempt has been made recently by Köhler to express it in terms of physicochemical principles. However the laws or operative principles which have been formulated by the Gestalt school are stated in phenomenal terms rather than in terms of neurophysiology, or in terms of the traditional psychological language. The theory was begun by Wertheimer as a result of his studies of movement perception. An illustration would be the case of the Cinema phenomenon already described. Wertheimer noted that the movement illusion could be produced by the alternate appearance of two shadows at disparate points and that the clearness depended upon the ratio between the 5 factors of intensity, size, shape, distance, and time. Of these, some increase and some decrease the effect. For example, he found that whereas intensity is disintegrative, distance is integrative; i.e., the greater the distance between the stimulus points, the more decided is the illusion. Integrative factors are those whose increase necessitates increasing the time interval, whereas disintegrating factors are those whose increase requires decreasing the time interval between stimulations. Wertheimer objects to the current explanations given for the following reasons: Explanations in terms of eye movements are usually ruled out because of the speed necessary. An added criticism would be that of Dodge that vision does not occur during eye movement. Titchener's theory that movement is a sensation caused by the weak stimulation of intervening points on the retina, producing a gray flash, is ruled out because such a gray flash would be absent in illusory motion, and the same explanation must apply to both real and illusory motion. A theory propounded by psychologists Marbe and Durr, that movement is failure to notice gaps between stimulations, was disproved by the fact that when attention is directed to the gap the appearance of movement is enhanced rather than destroyed. In place of these theories a physiological hypothesis is advanced which is directed against the idea of summations of stimulation effects. It is assumed that between any two processes in the optic sector set up by stimulation of two separate points on the retina, an attraction occurs. This is shown schematically in Figure 48.

When A is the first process and B the second, then B is attracted to A when the optimal movement time intervenes between the two processes. A physical analogy offered by Köhler is the following. Suppose a tank, in the bottom of which are two holes stopped with corks, is filled with water. If the stops are opened successively at an optimal interval, we get one whirlpool in the tank instead of two. At any other interval, two whirlpools result. It is assumed that in the optic sector there are attractions between processes whereby the resultant process is a function of the attractions between the various processes aroused. All illusions are accounted for in terms of such processes of attraction. For example, if two lights be flashed successively behind a screen at an optimal interval, there is an apparent movement from light A to light B in a straight line, but if an arc is placed above the lights then the illusory moving object seems to cling to the arc, taking a curved rather than a straight course. The explanation in Gestalt terms is that an attraction is set up between the processes aroused by the lights so that the resultant perception is distorted in the manner indicated. Configurationists, notably Koffka, refer to the fact that the clearest perception of illusory motion can be obtained from lights stimulating either side of the blind spot. This seems to be positive proof that the illusion is not due to intervening stimulations, since a blind spot intervenes. Since fatigue was found by Sander to decrease the optimal interval necessary to produce the movement illusion, it was assumed that

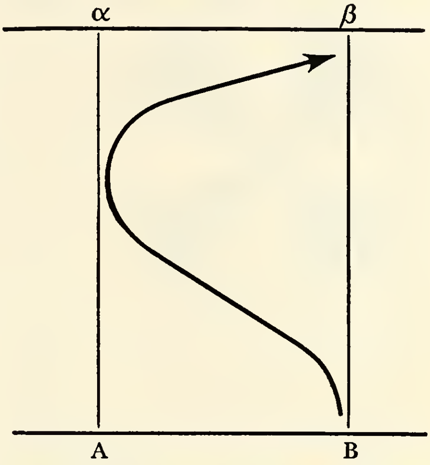


FIG. 48. The Phi phenomenon

any condition affecting the field of vision exerted an effect upon the resultant perceptual process. All such variations in the field are spoken of as field properties. For example, in cases of hemianopsia, when a simple figure of symmetrical shape is projected on the eye so that one half falls on the intact retina, the other half will be filled out or completed by the blind retina. However, if the figure is too complex this completion will not take place. These results were obtained by Fuchs working under Gelb and Goldstein.

This tendency for symmetry to be perceived in place of asymmetry is illustrated in other ways. For example, in the case of the flicker phenomenon, the rate of revolution of the wheel necessary to bring about fusion has been shown to be a function of the simplicity of the figure and the overlapping of the two alternating fields.

The same is true of the reversible figure phenomenon. The simpler or more symmetrical figure tends to appear first. An experiment was performed to determine the optimal time for fusion of figures of different complexity. The following measures were obtained: for the time of one revolution of the wheel, the circle gives 12.2, the hexagon 11.8, the square gives 11.2 and the triangle 11.2.

The apparent movement occurring between two points successively stimulated is called the beta movement. Another type of movement illusion called the gamma movement is that of expansion and contraction which objects display as a result of the conditions of the field at the time of exposure. For example, a lighted window appears larger than a dark one. The degree of effect is a function of the exposure time and the intensity of the stimulus. Points which show no movement when isolated tend to display movement when they become parts of figures. For example, in the case of the Müller-Lyer illusion, the expansion of the line is explained as due to the action of the properties of the surrounding field, or in other words, the attraction resulting from the stimulations produced by the arrow lines at the end. Again the effect is assumed to be a redistribution of energy resulting from the mutual interaction of processes aroused in the optic sector. The case of the autokinetic phenomenon would be accounted for in Gestalt terms as the attractive influence of the properties of the retinal field at the moment.

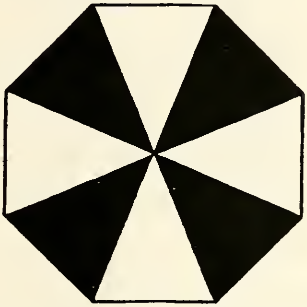


FIG. 49. Showing the relation of figure and ground

Another phase of the Gestalt theory has to do with the figure ground relationship in determining perceptual reactions to objects. It is assumed that in the perception of any Gestalt a distinction can be made between figure and ground properties. The more homogeneous, less intense, simpler parts of the total field of stimulation tend to form the ground, whereas the more intense, colorful, complex, heterogeneous and enclosed parts tend to form the figure. The identical stimulus may give rise to different perceptual properties, depending upon whether it forms a part of the figure or of the ground. Wertheimer has formulated six laws which have been observed to apply to the determination of the figure as opposed to the ground in a perceptual field. These laws are as follows: (1) the Law of Proximity; (2) the Law of Equality; (3) the Law of Common Fate; (4) the Law of Proper Continuation; (5) the Law of Closure; (6) the Law of Precision. These may be illustrated as follows: the Law of Proximity accounts for the fact that approximate points of stimulation tend to fuse into a figure more readily than disparate points; the Law of Closure describes the tendency to complete gaps in open figures and perceive the figure as closed; the Law of Continuation determines the fact that those lines which tend to continue or complete a direction already started will tend to be perceived as figure, rather than those which interrupt the continuation of such lines.

It is pointed out that we always get the simplest articulation, the best possible condition of equilibrium which the system is capable of establishing under the conditions of the moment. The factors contributing to figure simplicity are different from those which contribute to ground simplicity.

For example, the individual tends to perceive angles as right angles rather than as obtuse or acute angles, even though the latter are much more frequently encountered.

REFERENCES

Carr, H. A. The autokinetic sensation. *Psychol. Rev.*, 1910, 17, 42–75.

Carr, H. A. The pendular whiplash illusion of motion. *Psychol. Rev.*, 1907, 14, 169–180.

Dallenbach, K. M., & Guilford, J. P. A study of the autokinetic sensation. *Amer. J. Psychol.*, 1928, 40, 83–91.

Dodge, R. The participation of the eye movements in the visual perception of motion. *Psychol. Rev.*, 1904, 11, 1–14.

Dodge, R. Visual perception during eye movement. *Psychol. Rev.*, 1900, 7, 454–465.

Fuchs, W. Untersuchungen über das Sehen der Hemianopiker und Hemiamblyopiker. Teil I. Verlag erungserscheinungen. *Zsch. f. Psychol.*, 1920, 84, 67–169. Teil II. Die totalisierende Bestaltauffassung. *Zsch. f. Psychol.*, 1920, 86, 1–143.

Guilford, J., and Helson, H. Eye movements and the phi phenomenon. *Amer. J. Psychol.*, 1929, 41, 595–606.

Helmholtz, H. Handbuch der Physiol Optik., 2nd ed. Leipzig: L. Voss, 1896.

Higginson, G. D. Visual perception of eye movement. *Amer. J. Psychol.*, 1926, 37. 629–632.

Hulin, W. S. An experimental study of apparent tactual movement. *J. Exper. Psychol.*, 1927, 10, 293–320.

Hunter, W. S. The after-effects of visual motion. *Psychol. Rev.*, 1914, 21, 245–277.

Judd, C. H. The Müller-Lyer illusion. *Psychol. Rev. Monog. Suppl.*, 1905, 7, 54.

Koffka, K. Perception. *Psychol. Bull.*, 1922, 19, 531–585. Also New experiments in the perception of movement. *Int. Cong. of Psychol.*, 1923, 7, 369–374.

Koffka, K. The perception of movement in the region of the blind spot. *Brit. J. Psychol.*, 1924, 14, 269–274.

Köhler, W. Die psychischen Gestallten in Ruhe und in stationischer Zustand. Erlangen: *Welt Kreisverlag*, 1920, 1, 263.

Korte, A. Kinematoskopische Untersuchungen. *Zsch. f. Psychol.*, 1915, 72, 193–296.

Listing, J. B., & Donders, F. C. See Titchener, E. B. Experimental psychology, New York: Macmillan Co., 1901, pp. 246 ff.

Loemker, K. K. Certain factors determining the accuracy of a response to the direction of a visual object. Master's thesis, Univ. of Chicago, 1929.

Lotze, R. H. Medicinische Psychologie. Leipzig, 1852.

Purkinje, J. Beobachtungen und Versuche zur Physiol. der Sinne, 1825, 2, 60.

Stratton, G. M. Symmetry, linear illusions, and the movements of the eye. *Psychol. Rev.*, 1906, 13, 81–96.

Thelin, E. Perception of relative visual motion. *J. Exper. Psychol.*, 1927, 10, 321–349.

Titchener, E. B. A textbook of psychology. New York: Macmillan Co., 1924.

Wertheimer, M. Untersuchungen zur Lehre von der Gestalt. I. *Psychol. Forsch.*, 1921, 1, 47–58. II. *Psychol. Forsch.*, 1923, 4, 301–330.

Wohlgemuth, A. On the after-effect of seen movement. *Brit. J. Psych. Mon.*, 1911, 1, 1–116.

Wundt, W. Grundzuge der Physiologischen Psychologie. Leipzig: Engelmann, 1880.

CHAPTER VIII

AUDITORY SPACE: TIME PERCEPTION

ACTUALLY, the perception of spatial location involves the close coöperation of visual, auditory, and motor cues, so that we cannot speak of auditory as distinguished from visual space. But there are distinct auditory cues which could theoretically operate in the absence of vision, and which do so in the case of the blind. Hence auditory localization is a distinct problem.

The two main features of auditory space are distance and direction. Size and shape are certainly of minor significance, while motion has not yet been experimentally studied.

Distance. — There are two major cues to the perception of distance: intensity of the sound, and tonal complexity. The physical law for intensity is as follows:

The more distant the vibrating object or source of the sound, the less intense is the stimulation of the ear.

The psychological law is the reverse of this: The less intense the sound sensation, the more distant is the vibrating object perceived to be. It is assumed of course that the intensity of the source is a constant. Any variation in this would distort the judgment. Judgments based on intensity are subject to error due to conditions of the atmosphere, just as are those based on brightness in vision. Under certain atmospheric conditions, distant sounds are louder.

The physical law relating to tonal complexity is as follows:

The partials are always weaker than the fundamental tone in a klang. Therefore the more distant the source of the sound, the fewer partials are audible.

The psychological law is the reverse: the fewer the partials heard in the klang, the more distant is the source of the sound perceived to be.

It follows as a by-product of this that klangs which contain fewer partials, or pure tones like those from a tuning fork, are judged to be more distant. This accounts for the far away sound of tuning forks; and the ventriloquist's illusion of distance produced by a thin voice lacking resonance of partials.

Direction. — Whereas the auditory perception of distance is mediated entirely by monaural cues, some of the cues to *direction* result from the fact that we have two ears — the binaural relationship. The difference in the character of stimulation of the two ears resulting from a single source of sound is known as the binaural ratio. This difference exists only for sounds whose source is either to the right or left of the median plane of the head. It does not pertain to sounds whose source is in front of or behind the parallel plane of the body, nor to those whose source is above or below the horizontal plane of the head. Monaural cues aid in the latter cases. But binaural differences may be brought into play by twisting the head on its vertical or horizontal axis so as to stimulate the two ears differently. Consider the situation in which the head is held stationary with eyes front. The following main cues operate:

(a) Intensity ratio
(b) Complexity ratio
(c) Time ratio
(d) Phase ratio
(e) Angle of incidence

When the two ears are stimulated by a vibrating body, two separate stimulations occur, even though they are centrally fused into a single sound experience. The two stimulations differ when the vibrating body is situated anywhere but in the median plane of the head. In the latter case the stimulations are equal in all respects. Otherwise the sound is louder in the ear on the same side as the object. The further the object is from the median plane, the more pronounced is the binaural difference of intensity.

Likewise, the stimulation is more *complex* in the ear on the same side as the source. This follows from the relation between complexity and nearness.

Since it takes a sound wave an appreciable time to travel to the ears from the source, it will reach the nearer ear first. This causes a slight difference in the time at which the two ears are stimulated. This is known as the *time ratio.*

Phase ratio refers to the fact that, when the sound wave has a different distance to travel to the two ears, it reaches them in different phases. It may reach one ear at the condensation phase, or crest, and the other at the rarefaction phase, or trough.

The angle of incidence cue assumes that the sound waves from a single source would necessarily approach the two ears at different angles. Provided the angle of incidence affects the character of the stimulation received, then the aforesaid difference would give a cue to the direction of the source.

Experimental Proofs

The effectiveness of each of these factors can be demonstrated by experimentally isolating each and varying it.

Plugging. — The intensity of the stimulation in either ear can be reduced to any desired degree by plugging that ear. If, then, the source of sound is in the median plane, it should be erroneously perceived to be on the side opposite to the plugged ear. And the distortion should bear a quantitative relation to the amount of reduction in intensity, complexity, etc., caused by the plugging. This is found to be the case. Clinical evidence corroborates this by showing that subjects whose hearing has been partially lost in one ear tend to consistently misjudge the source of sounds, with a constant error in the direction of the intact ear. This sometimes clears up with long practice, because they learn to compensate for the error. The method of plugging alters intensity and tonal complexity only.

Tube conduction. — If the sound waves are conducted through tubes from the source to the ears, it is possible to vary phase ratio and time ratio in addition to the other two. The source of sound is in the median plane. But one of the tubes is made longer than the other, so that the sound wave has to travel farther to reach one ear. This alters its intensity and complexity and at the same time alters the time of stimulation of that ear and consequently the phase. In this case, the subject makes false judgments as to the location of the source.

Fusion of stimuli. — If two sounding bodies are used, provided the tones are of similar pitch and quality, they will fuse and be heard as one tone. Now if the stimuli are placed equidistant from the median plane of the head, the source will be judged to be a single sounding body located in the median plane. But if either stimulus is made weaker than the other, the subject will judge that the sounding body has been moved in the opposite direction to it.

The "Pseudophone." — P. T. Young demonstrated the function of the binaural ratio in perception of direction by constructing an instrument which conducted the sound waves to the opposite side of the head from the normal. This was accomplished by extending a sound proof tube over the head from each meatus, with an artificial pinna at the end of each tube. Thus the right ear received the waves which the left ear would ordinarily receive and vice versa. When the experimenter wore this 'pseudophone' continuously, at first all sounds were wrongly localized. Noises whose source was to the left were reacted to as if to the right, etc. As far as purely auditory localizations were concerned, without the aid of vision, this wrong localizing tendency persisted

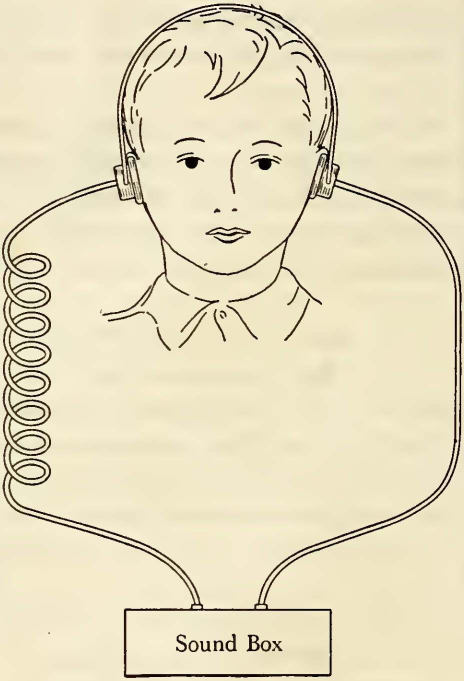


FIG. 50. Apparatus for tube conduction

throughout eighteen days of habituation with no change. But when vision was permitted, the wrong localizing tendency was soon compensated for and normal reactions occurred. When the "pseudophone" was finally removed, normal localizing reactions occurred at once, and there was no such period of disturbance as Stratton describes for vision. It is therefore concluded that vision plays an important rôle in normal auditory localizing reactions.

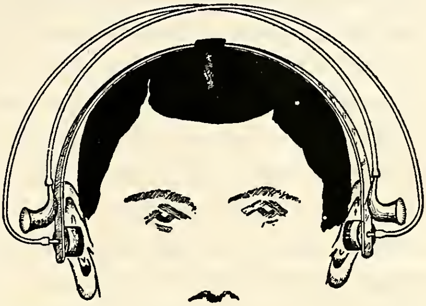


FIG. 51. The Pseudophone
From Young

Vision may affect auditory localization in several ways. First, there is usually some visual cue to the sound's source, such as movement of a speaker's lips or swinging of a bell. Ventriloquists make use of the movement of the wooden doll's jaws to deceive the audience as to the source of the voice. Again, the character of the sound helps the subject to look for its source and thus localize it. The author finds himself relatively deaf without spectacles. Again, vision directs the head, and head movements correct auditory judgments by varying the binaural ratio.

Monaural Cues

That some monaural cues aid in perception of direction is shown by the ability of persons, who are stone deaf in one ear, to judge direction. J. R. Angell, experimenting with such clinical cases, reports that the extent of reliance on monaural cues varies with the period of deafness. Those longest deaf utilize them best.

Cutaneous Space Perception

Strictly speaking, only two space characters are perceived cutaneously, location of points on the surface of the body, and extensity in two dimensions. However, if movement of the hand over an object is allowed, three dimensions can be appreciated. And if two or more disparate points on the surface of the body are successively stimulated at an optimal interval of time, real or illusory motion is perceived.

Local Sign. — The first problem concerns the accuracy with which a spot on the skin can be localized. This varies with the area. On the finger tips accuracy is as high as a millimeter error. On the back and shoulders, the error is much greater, as large as two inches. The main theory to account for the ability to localize at all is that each different area of the skin, when stimulated, gives rise to a unique and characteristic sensation. The theory is attributed to Lötze and is called the " local sign " theory. The greater vagueness of certain areas would be attributed to the smaller number of cutaneous nerves from these areas, and the fewer distinct sensory experiences per unit of area as a result. These " local signs " need not be conscious. This is demonstrated by the fact that decerebrated dogs can make rough localizing movements of the limbs, as in scratching an area to which acid has been applied. Here there seems to be a reflex connection between the area stimulated and the localizing movement. But normal dogs are capable of making much more accurate localizations.

The actual capacity to localize accurately is not native. An association must be established between the particular " local sign " and the localizing movement, and this requires a trial and error process.

✓ *The " Two-point Threshold."* — The other problem is that of the perception of extensity. How well can we judge the distance apart of two points of stimulation? This also varies with the skin area and is closely correlated with the localizing capacity. It has been determined that if two points on the skin are simultaneously stimulated, they must be separated by a certain minimal distance to be perceived as two rather than one. This distance is known as the " two-point threshold," and is smallest on the finger tips and greatest on the back and shoulders. The method of studying the two-point threshold quantitatively by means of an adjustable aesthesiometer has been described previously. At least three stages are observable, as the points are moved farther apart; first a stage in which the points are felt as a round surface;

second, one in which the round surface is elongated into an oval surface and third, a complete separation of the two experiences.

Other Senses. — Mention of the rôle of the kinaesthetic and static senses should not be neglected. The appreciation of space dimensions is largely built up from making motor adjustments to them and the kinaesthetic impressions resulting. Weight and shape are largely appreciated through kinaesthetic strains.

One of the aspects of space perception is the capacity to orient one's body in space; the capacity to judge whether one's body is vertical or horizontal, and whether it is stationary or moving and in what direction. This is the function of the static sense. The semicircular canals are the sense organs of equilibrium, but judgments made without the help of other senses, particularly vision, are quite inaccurate. This can be demonstrated by means of an instrument called the "rotation and tilt table" designed by Sanford and Scripture. The subject is strapped to a horizontal board which is mounted on a fulcrum base and can be either rotated, or tipped so that the subject's head or feet are highest. If the subject is blindfolded, and asked to judge at what angle he is lying, his judgments will show a large error. Judgments made while standing still or while moving at a constant rate are poor. But judgments of a change in speed or a change in position in space are more exact. This is due to the fact that the semicircular canals are stimulated by changes of the position of the head which cause a disturbance of the inertia of the liquids. Such judgments are always aided by cutaneous and intraorganic sensory cues.

Time Perception

Time consists of a unidimensional series — protensive magnitude. The chief problems of time perception are (a) to determine the time thresholds, the shortest and longest intervals which can be perceived, and the differential threshold, or how large the difference between two time intervals must be to be distinguished; (b) to discover what factors cause time intervals to appear longer or shorter; and (c) to explain the perception of rhythm.

Time sense has both a lower and an upper threshold. The shortest interval between two stimulations which can be appreciated, so that the stimulations do not fuse and appear simultaneous, varies with the sense organ. If both stimulations affect the same sense, the threshold may vary from 2–20 sigma for hearing and touch, to 40–100 sigma for vision. When the stimulations are of different senses, the threshold varies from 30–150 sigma. Moreover a continuous stimulation must last about this time in order to be perceived as having duration, and not as instantaneous. On the other hand the upper threshold — i.e., the largest interval which can be directly perceived as a unit is from 4 to 5 seconds at the maximum. Longer intervals are the product of judgment or estimation.

The differential threshold is the least difference between two intervals which can be detected. This is a very small fraction of a second, but the optimal duration of an interval for comparison purposes is a half second; longer intervals than this are underestimated and shorter ones overestimated. However, if a group of sounds is arranged in a rhythmic series it is simpler to detect slight differences in terms of the rhythmic pattern.

The explanations of how time is perceived differ. But introspective evidence favors a theory based on muscular strains. If the interval to be estimated is bounded by two clicks, when the first click is given, we assume an attitude of expectant attention, probably involving actual motor strains. The second click brings release from the strain; hence the amount of strain which develops is a rough quantitative equivalent of the length of the interval.

However, longer intervals of time are judged differently. Time is, in essence, change, and long stretches are divided into a series of changes. Any recurrent change aids judgments of long time stretches. Probably physiological rhythms, as the heart beat or breathing, are involved in such estimations. It is interesting that filled time is overestimated in comparison to unfilled or empty time, just as is filled space. But it is in retrospect rather than in immediate experience that this is true. Time spent in idle waiting is, at the time, very much overestimated.

Rhythm presents unique problems, in that the perception is always with a series of stimulations interrelated according to some pattern. If the external stimuli have no pattern, the subject tends to impose a pattern of his own, by accentuating certain stimuli. Judd found that most subjects tend to impose rhythms or groupings on a series of auditory clicks in counting them, and by this method can count series of fifteen or twenty clicks delivered at the rate of eight or nine per second. Woodrow reports that if, in a series of equally spaced sounds, certain sounds are more intense, as every third or fourth, the intense sound forms the beginning of the rhythmic group. It is practically certain that kinaesthesis is the most important rhythm sense, and that motor tendencies are the most important elements.

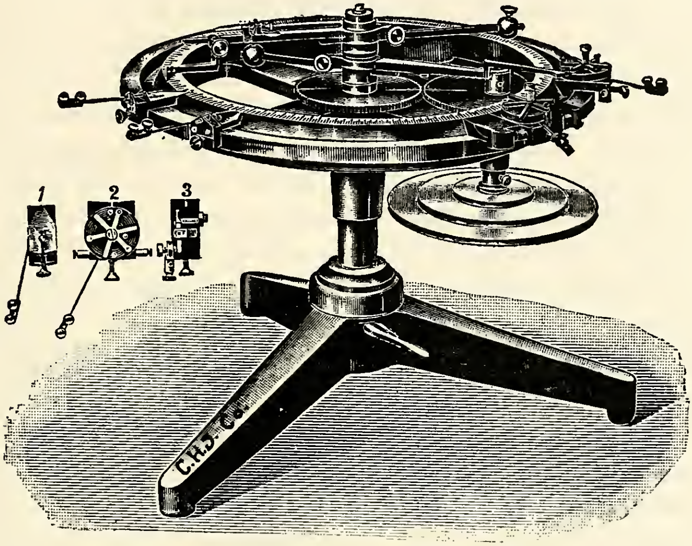


Fig. 52. Time sense apparatus

Courtesy of C. H. Stoelting Co.

Experiments in Time Perception

The two main methods used in experiments with time perception are (a) the method of reproduction, and (b) that of comparison. According to the former method an interval is presented and the subject is asked to reproduce it immediately thereafter. According to the second, two intervals are presented, and the subject must judge whether the second is longer or shorter than the first. Two such intervals might be marked off by three clicks, where the middle click both terminates the former and begins the latter interval; or four clicks may be used with a pause between each pair.

The apparatus used for refined work is the Wundt time sense apparatus, consisting of a radial arm which revolves at a constant speed around a stationary circle. The end of the arm is equipped with an electrical contact which is adjusted to work with points on the stationary circumference of the circle. These points are adjustable so that they can be placed wherever desired on the circumference. In this way, two or more clicks can be temporally spaced at the necessary distances apart. If the arm revolves rapidly, very minute differences in temporal spacing can be produced. A modern technique used by Seashore for testing time sense and sense of rhythm utilizes the phonograph record for production of the clicks or stimuli, in accordance with a prearranged order of presentation.

The Indifference Interval. — Since short intervals are underestimated and long ones overestimated, there is a point between these extremes which will usually be estimated correctly. Münsterberg reported that more than one of these indifference intervals occur, which are roughly multiples of 700 sigma, the shortest indifference interval.

REFERENCES

Angell, J. R., & Fite, W. The monaural localization of sound. *Psychol. Rev.*, 1901, 8, 225–246, also 449–458.

Halverson, H. Binaural localization of tones as dependent on differences of phase and intensity. *Amer. J. Psychol.*, 1922, 33, 178–212.

Judd, C. H. Laboratory studies of arithmetic. *Stud. Educ.*, 1925, 23–28.

Judd, C. H., & Buswell, G. T. Summary of educational investigations related to arithmetic. *Suppl. Educ. Monog.*, 1925, 27, 1–212.

Münsterberg, H. Grundzuge der Psychologie. Leipzig: Barth, 1900.

Woodrow, H. A quantitative study of rhythm. *Arch. Psychol.*, 1909, 14, 1–66.

Young, P. T. Auditory localization with acoustical transposition of the ears. *J. Exper. Psychol.*, 1928, 11, 400–429.

Part Three—Learning and Memory

SECTION A—LEARNING

— Final
9-10-11-12-13
14-15-16

CHAPTER IX

NATURE OF THE LEARNING PROCESS

LEARNING is the most fundamental psychological phenomenon since it is the basis on which the entire superstructure of complex mental behavior is erected. The most inclusive definition of learning identifies it with all modifications of behavior. However, it is necessary to exclude from this term those modifications which result from (a) changes in structures outside of the nervous system, as sensory or muscular development or skeletal growth, (b) changes within the nervous system resulting directly from maturation, and (c) those resulting from fatigue, and temporary alterations of thresholds of excitability. This leaves the entire group of relatively permanent modifications in behavior patterns which result from previous interaction with the environment, to be designated learning.

There is a fairly imposing body of factual data with regard to the behavior side of learning. Experimental analysis has settled, with relative finality, many questions regarding the economy of effort in learning, and the stimulus-response factors involved. But our understanding of the underlying neural mechanisms has not kept pace. The entire problem is in a largely speculative stage. Psychologists are in much better position to state what learning is *not* than what it *is*. The theories based upon hypothetical properties of the synapse, lowered resistance, retentiveness of tissue, and the like, and those which imply neurogram patterns of some sort, are more truly to be characterized as logical necessities of thought than as empirical facts.

THE PHYSIOLOGICAL BASIS OF LEARNING

There are three main sources of information regarding the neural basis of learning: (1) The correlation of the development of brain structure with development of learning capacity in the phylogenetic series; (2) a similar study of ontogenetic development; and (3) a study of the general relations between brain structure and the learning function, in disease, injury, etc.

Phylogenetic Development

Experiments upon unicellular animals, and those lacking a true nervous system, as Jenning's study of the stentor, show a summation of the effects of a series of stimulations, resulting in a modified reaction, but the effect does not persist, to form an acquired change in the pattern of response. With the appearance of a synaptic nervous system, acquired responses are in evidence, even at the level of the earthworm, as Yerkes demonstrated. From this point on the main direction of development seems to be, not toward an increased speed of acquisition of simple habits, but rather toward a tremendous increase in the number and complexity of the habits which can be acquired. This development of learning capacity closely parallels the development of the cerebrum in vertebrates. A host of experiments on mammals demonstrates the fact that ability to solve more subtle problems develops along with the increase in relative size of the projection areas and frontal region.

Correlation of Structure with Function

Lashley has demonstrated by extirpation experiments on rats, a close relationship between learning ability and quantity of available cortical tissue. He got a correlation of .86 ± .03 between extent of injury and number of errors made in learning a maze. But even a rat with an 80% destruction could still improve slightly.

In the learning of problems like the maze, there is apparently an equipotentiality of the different regions of the cortex, but with visual discrimination habits, reaction to pattern is specifically a function of the occipital area. In man there is apparently much greater specificity; e.g., an intact speech area seems to be necessary for facility in the formation of verbal associations.

The assumption of some sort of localized pattern in the cortex corresponding to an acquired reaction pattern is logical, yet in rats the only regions which have yet been proved to be specific to the retention of a given acquired habit are the occipital area for visual discrimination habits, and possibly the temporal area for auditory habits. This may mean that *multiple* patterns are established or that the pattern is *non-spatial,* consisting in some characteristic periodicity in the neural processes involved, or some other spatially indifferent kind of pattern.

That the acquisition of reaction patterns involves reduction in the resistance of the synaptic junctions between cells is a well established hypothesis and there are certain facts about nerve action which lend support to it. For instance, (1) The synapse is the point at which diffuse conduction to many cells is possible. (2) The polarity of the nerve is determined at the synapse, since simple nerve fibers may conduct in either direction. (3) The continuity and relative homogeneity of the conductive tissue within the cell suggests that delay in transmission and differential permeability are functions of the intercellular membrane. (4) The greater susceptibility of the synapse to certain toxic substances. (5) The barrier to deterioration set up at the synapse, whereby the degenerative process, in a nerve fiber, will not pass it. All these facts suggest the synapse as the region capable of sufficient modification to make possible the difference between the readiness of learned and unlearned reactions.

On the other hand, the evidence against strict localization applies also to the synapse hypothesis. If the synapse theory is to be credited, the additional assumption must be made that the modifications in synaptic resistance following learning are widespread and not confined to any limited region, such as the tracts involved in the identical performance of the act. Otherwise, a learned pattern could not be performed interchangeably by a large number of different receptor and effector organs.

The evidence from study of lesions in humans does not support the notion of strict localization. The findings of Franz on motor disturbances, of Goldstein on visual defects, and of Head and Jackson on aphasias point to a loss of general facility within the functional field rather than the disappearance of specific mechanisms.

Neural Theories of Learning

There are two classes of theories, (1) those which attempt to explain the facilitation in performance of a given act as a result of repetition, and (2) those which account for new pathways of discharge, as in the conditioned response. The former class assume some structural change in nerve cell or synapse causing decreased resistance to the passage of impulses and a resulting greater readiness for the act to be performed. The latter theories are supplementary to the former and assume some sort of mutual influence of neighboring arcs on one another. McDougall's drainage hypothesis is widely appealed to. The essential concept in the hypothesis is that when one neural arc (A) is stimulated, the resistance within it is lowered so that if some other arc (B) simultaneously is excited the resulting excitation will be attracted to the arc already functioning, and a new integration will result, such that stimulation of (B) will now elicit the response which originally occurred only to stimulation of (A).

Various irradiation theories, and theories of fields of force or metabolic or electrical gradients are designed to give a more up-to-date formulation of the above principle, which will escape the assumption of an actual hydraulic distribution of nerve energy.

Theories which are definitely antagonistic to the concept of integration of isolated arcs, substitute the general notion of unit functioning. The Gestalt theory and the equipotentiality theory of Lashley are of this class; the former being developed from logical considerations, the latter based on studies of cortical functioning.

The facts of association point to a widespread diffusion of the effects of stimulating a particular reaction system. It is not so important, at present, whether this diffusion of effects is explained in terms of McDougall's drainage hypothesis or by an irradiation hypothesis, or a concept of equipotentiality. The evidence is insufficient to decide. But the important fact is the widespreadness of the effects and the consequent inadequacy of a rigidly spatial concept of the neurology of learning.

PERCEPTUAL MOTOR LEARNING

For convenience of study, learning may be differentiated into two types; (1) perceptual motor learning or the formation of habits or acts of skill, and (2) ideational learning or memory. These categories are not exclusive. Thus, in the main, habit formation involves the fixation of definite response patterns so that the actual movements are later reinstated, whereas memory involves the establishing of a symbolic substitute for the original process, which is later revived and functions in the absence of the original. Yet the memorizing of a poem is in part the mere acquisition of a vocal habit, and the learning and reinstatement of acts of skill are greatly facilitated by the symbolic processes which accompany the learning. Swimming is an act of skill, yet one can shorten the learning process by symbolically thinking about the correct movements.

Typical Problems and Methods of Experimentation

Animal Studies

Why has such an extensive use been made of animals in learning studies? Aside from the fact that animal learning is a legitimate problem in itself, it is important to students of human learning, (1) because of the phylogenetic assumption, i.e., that the human learning process is an evolutionary product of animal antecedents, and (2) because the essential elements of complex processes like learning are best studied in their simplest form, i.e., in the animal situation where they are uncomplicated by anthropomorphic presuppositions. An additional reason is the fact that many experiments can be performed on animals which would be impossible with human subjects, such as extirpation studies.

There are certain features which are common to the majority of animal experiments. First, the animal is *motivated;* either by hunger or some other exciting condition. The means of satisfying this motive, i.e., food, constitutes the incentive. The problem, for the animal, then, consists of learning to overcome some obstacle in reaching the incentive.

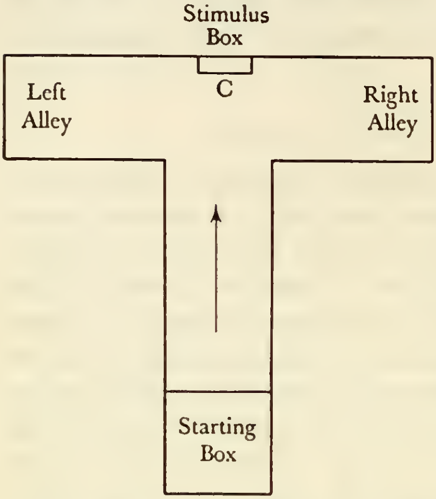


Fig. 53. "T" maze for discrimination habits

Characteristic types of animal study are the following: *Discrimination Habits.*—The animal learns to choose between two possible responses in terms of a sensory discrimination. In its most common form, the Y or T maze, schematically represented in Figure 53, the animal is presented with one of two possible visual stimuli at C. For example, if a light is flashed, food will be found to the left; if no light appears, the food will be found to the right. Such problems can be learned by a wide range of organisms. The kind of stimulus used depends on the sensory equipment of the animal. Consequently the method can be used to determine the sensory acuity of any particular type of animal. Sometimes, instead of a positive reaction, an avoidance reaction may be set up, by placing a grill at the entrance to one of the side alleys, and punishing the animal for wrong responses. A recent modification of the discrimination experiment has been introduced by Lashley, to speed up the learning process. Instead of being released from the end of a long runway, as in the diagram, the animal is placed on a platform from which he must jump through one or the other of two trap doors, depending on the stimulus displayed on it. This method cuts down the learning time with rats from over 500 to under 50 trials. Problems such as geometrical discrimination can be learned by this method only.

Maze Experiments. — The animal maze consists typically of a labyrinthine series of pathways, one of which is correct, leading to a food compartment; the other paths lead off from the correct one and end blindly, in culs-de-sac. The maze type of problem has many advantages. It is adapted to a large range of organisms; it can be varied in difficulty merely by lengthening the path and increasing the number of culs-de-sac indefinitely. It offers four different criteria of improvement from which the rate of learning can be computed: total trials, time per trial, errors per trial, and distance run. It is analytical, and is therefore especially adapted to the study of the trial-and-error type of learning, since the separate steps in the process are spatially and temporally distinct. It has been criticised by Hunter on the ground that it is an unreliable measure of learning ability, due to the variability in individual performance from maze to maze; but Carr has defended it on the ground that this individual unreliability does not destroy the validity of group comparisons. Probably the greatest objection is that it has both oversimplified and overcomplicated the learning situation, and led to a too mechanical interpretation of the process.

Problem Box. — This was introduced by Thorndike. The animal is placed inside a box, or cage, equipped with a latched exit which can be manipulated from within. Food is placed outside the box. The animal learns by repeated trials to open the exit. More often the food is inside the box and the animal outside.

The Multiple Choice Problem. — Yerkes introduced this method. A certain number of food boxes arranged in a row is presented to the animal. Food is in one of the boxes, say, the second from the right. In a series of presentations, in which the number of boxes presented is systematically varied, the animal has to learn always to go to the second from the right, to get food. The problem may be made so complicated that it is practically unsolvable, even by human subjects. Hunter used a multiple choice technique in studying the delayed reaction. In this case, however, success depended on remembering the position of the correct box for a time after the cue had been given.

The Alternation Problem. — A simple Y or T maze is used. The animal must learn to go first to the right, then to the left, alternately. More complicated alternations can be used, such as " once to the right, twice to the left, once to the right," etc. But the simple right-left alternation is learned with extreme difficulty by rats.

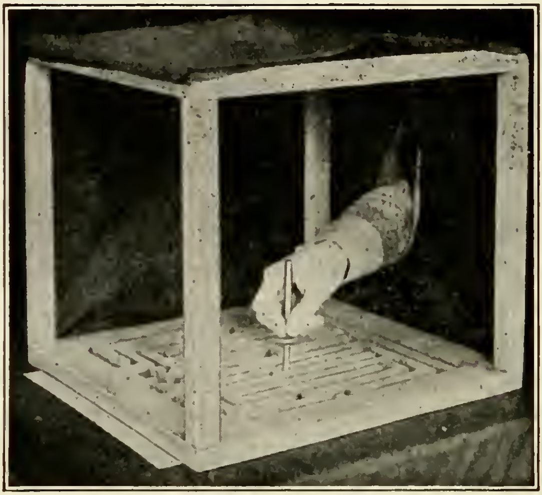


FIG. 54. Human stylus maze

Courtesy of C. H. Stoelting Co.

Other Problems. — A variety of experimental set-ups has been used by Köhler on apes. These are variations on the problem box idea but they are designed to bring out more clearly the principle of insight, use of tools, ideas, and the like.

Human Studies

These range all the way from ball tossing to the solving of complicated mechanical puzzles, or learning to speak a foreign language. In general, they involve the acquisition of skills. They may be roughly classified into three groups.

(1) Studies in which the motor element predominates.

Target shooting, archery, javelin throwing, ball tossing and throwing, moving the ears, tight-rope walking, etc.

(2) Studies in which the intellectual element predominates.

Learning foreign languages; psychophysical judgments of weights, lengths, etc., used by Thorndike and Woodworth; playing chess; solving puzzles, such as those used by Ruger, in which the solution involves insight into the logic of the problem; and Peterson's rational learning type of test.

(3) Studies in which both motor and ideational factors are important.

This is the largest group. It includes studies of telegraphy such as Bryan and Harter's; studies of typing and shorthand, like those of Swift and Book; studies of stylus maze learning; of mirror tracing; of card sorting by Pyle, Culler, and others. Many memory studies contain elements of perceptual motor learning.

THE STEPS IN PROBLEM SOLVING

THE typical perceptual motor learning situation, whether animal or human, involves certain essential features. First, there is a *problem* — i.e., a situation to which the subject is not adequately adjusted, and toward the solution of which he is motivated. The solution, then, is the discovery of a mode of adjustment, the adaptation of means to end. When the correct act is hit upon there occurs a process of fixation, or selection and elimination by repeated trials. The perfected act is then *retained* until such time as it is *reinstated* later, or *generalized* for use in new situations.

The Methods of Solution

It is necessary to distinguish between problem solving with and without tuition, for most human learning is of the latter class. The typical unassisted solution is called a *trial and error process* because it consists in trying out several suggested possibilities until one of them proves successful. Since the subject has no pre-knowledge of which act will prove to be successful, it is said to be a *chance success*. A distinction is commonly made between *motor* and *ideational* problem solving, the latter being identified with reflective thinking or reasoning. But the ideational method still makes use of trial and error. The only difference is that ideas are used as symbolic representatives of overt acts or situations, and the trial and error process becomes a process of ideationally trying out one method after another until the correct method is discovered. The Gestalt school has objected to the trial and error hypothesis on the ground that often, both in motor and in ideational problems, the solution comes at once without any such process of cutting and trying. Tolman has objected that there is always some vague foresight of the goal and that this becomes less vague during the process of solution. Köhler insists that even the animal may have *Einsicht,* or an appreciation of the logic of the situation, in terms of which the solution is made.

The objections seem to be directed mainly against the notion of a completely *blind* trial and error process with a purely chance stumbling upon the successful act. This arises perhaps from a too rigid interpretation of the *random* nature of the trial and error, and of the *chance* nature of the success. But Carr has emphasized the fact that the so-called random attack is always *relevant* to the problem. Each act in the series is one which has proved successful in previous situations of a similar nature. This might be explained as due to an appreciation of the problem situation, and hence to involve at least a vague *insight* into the problem, although it might also be interpreted as a mere setting off of previously conditioned responses by the stimuli inherent in the situation. For example, a rat confronted with a food cage is stimulated by the sawdust to dig and by the wires to gnaw, etc. Carr has also pointed out that the appearance of the successful act is only chance in a limited sense. There are a limited number of possibilities for relevant acts. It is only a matter of time, therefore, before the correct one will be hit upon, provided the solution is within the capacity of the organism, and the attack is sufficiently persistent and variable. Probably in the case of higher organisms, like the human, the entire process is accompanied by a growing insight into the solution and hence a narrowing down of the possibilities and an increased relevance of attack. Tolman has emphasized this feature. A study of the problem-solving behavior of pre-school children by Alpert, however, emphasizes the fact that what she calls the "exploration and elimination" type of response is the most frequent, though pure random responses do occur, as do also "immediate responses" in which the solution is unpreceded by overt exploratory trials. She postulates a gradually increasing insight. A further discussion of the point will be postponed to the chapter on Thought.

Learning with tuition is the typical educational method. Tuition may take several forms. It may involve *"putting through"* the correct solution and incidentally eliminating the errors; or *verbal instruction* of one sort or another; or demonstration, with *imitation* on the part of the learner. The last method requires a high degree of sophistication on the subject's part. It is probably not characteristic of animal learning nor of infant learning. It apparently requires the ability to verbalize and to represent ideationally the series of observed steps in the solution. Attempts to discover intentional imitative behavior in apes and in very young children have proved inconclusive.

The Process of Fixation

Once the correct act which solves the problem is hit upon, that act is eventually fixated and the various incorrect acts eliminated. The explanation of how this takes place constitutes one of the most disputed problems of learning, and one which has stimulated much experiment. As a result several theories of selection and elimination have been formulated. All of them employ one or more of the fundamental concepts: contiguity, use, and effect. In fact, contiguity and use might be reduced to phases of the effect principle. Certainly, purpose and will are to be classed as forms of the effect principle.

Theories based on contiguity and use

(a) One of the earliest formulations is that of Thorndike. His law of exercise or use, when accompanied by the correlative law of disuse, is based on the general fact that an act is strengthened by repetition and weakened by disuse. Critics of the law point out that the result of repetition is always a function of the kind of *effect* produced by each repetition. Carr points out that the oftener an unsuccessful or painful act is repeated the more quickly does it disappear, and Dunlap bases a therapeutical technique for eliminating bad habits on the same principle. Students of the conditioned reflex report that the oftener it is elicited without the accompaniment of the original unconditioned stimulus the more rapidly will it disappear, and this is known as the law of experimental extinction. Woodworth would place these cases under the principle of negative adaptation. Probably the "effect" in theses cases is such as to elicit an avoidance reaction. In other words, the thing that is fixated by repetition here is the habit of avoiding or inhibiting the action in question; hence it is still true that repetition fixates. In the last analysis, however, repetition reduces to effect since it is merely the way by which more effect is obtained, or by which the effect is intensified.

(b) The conditioned reflex hypothesis, implicit in behaviorism, and formulated for learning by Smith and Guthrie, is based on the principles of contiguity and use. When conditioned and unconditioned stimuli are presented contiguously and repeated often enough, the conditioned response becomes fixated. In addition, the fact is emphasized that the bonds are established on the motor side of the arcs. But the conditioned reflex hypothesis as a prototype for all learning, or even much of it, is justly criticized on the ground that its characteristic attributes are incompatible with the facts of learning. Conditioned reflexes are often difficult to establish, requiring laborious repetition, and, once established, they soon fade out.

(c) The laws of frequency, primacy, and recency were incorporated into Watson's mechanical theory of learning. He gave a mathematical demonstration of their adequacy in the absence of other factors, while not actually denying the existence of other principles. In the maze, the correct path was shown always to have the advantage of frequency and recency over all other paths. But the maze situation is a limited one, and more recent maze experiments, in which frequency and recency were intentionally ruled out of the situation, yielded success. Peterson showed, in a series of experiments in "mental" maze learning, that "agreement with recency has no relation at all to the rightness of the response, and in the case of frequency, agreement with the law is somewhat more likely to occur in the wrong than in the right responses while disagreement is more likely to be found in the right than in the wrong responses." Recency is at best a weak explanation, since the successive acts in a problem solving situation often come so close together that a few seconds only intervene; yet the next trial is a day off. What is a difference of recency of a few seconds against a day's intervening delay? And, even so, the successful act is not always the last.

Theories based on the concept of effect

Lloyd Morgan's pleasantness-unpleasantness theory grew out of observations of the kind made by him on the behavior of chicks toward cinnabar caterpillars. The chicks are supposed to avoid the striped caterpillars because of the remembered unpleasantness of their previous experience of tasting them. Hobhouse criticized the theory because it assumes that an act can be *fixated* by what occurs after it has taken place. In general, the theory involves the assumption of representative thinking and violates the canon of parsimony in explanation.

Thorndike's principle of satisfyingness of consequences is related to the pleasantness-unpleasantness theory, provided satisfyingness is interpreted as an affective consequent of the successful act, which stamps it in. As such it has the same flaws. But it is possible to interpret satisfyingness objectively as "fulfilment or removal of the organic conditions which initiated the act." Thorndike has recently suggested that the neural correlate of his theory is a reinforcement process.

Peterson has cast doubt upon the pleasure-pain theory of fixation and elimination by setting up an experimental situation in which right responses were punished by an electric shock, and wrong responses were not punished, in the mental maze. Learning took place under these conditions, and in the later trials, the punishment for right responses proved actually beneficial as a guide to the subjects.

Carr has suggested "*sensory consequences*" in place of affective or other hypothetical effects, since it is obvious that each act does have sensory consequences on the basis of which selection is made. The problem still remains, however, of explaining how the sensory consequences operate. Troland has attempted this task in his formulation of the concept of nociceptive and beneceptive stimulations. It rests on the assumption of a native tie-up between sensory stimulations of a given sort, i.e., nociceptive, and avoidance or inhibitive reflexes. A similar automotive connection is assumed between beneceptive stimulations and positive or facilitating reflexes tending to reinforce the action.

Hobhouse's confirmation-inhibition theory and the congruity theory of Holmes postulate positive and negative reaction tendencies awakened by the kind of stimulation resulting from each act, and a consequent reinforcement of correct acts and inhibition of incorrect ones.

It has been suggested by Carr and others that the conditions, under which certain acts occur, involve an "*intensity*" whose neural and metabolic counterparts tend to reinforce such acts. This is similar to the principles of vividness and intensity in association theory. It accounts for the rôle of the sensory consequences in learning.

Peterson's completeness of response theory conceives of all the acts in response to a problem situation as being energized by a common driving force, i.e., the motivating condition. The selection or elimination of part acts is then explained in terms of their contribution to the final completeness of the response as a whole which removes the motivating condition.

The principle of effect is probably the central explanatory principle in learning. It is in the detailed application of the principle that psychological theories are at variance.

The purposive and insight theories

These are alike in that they utilize the concept of some sort of influence exerted on the fixation process by the goal or end sought.

A group of psychologists, among whom the names of Woodworth, Perry, and Kuo (formerly) are prominent, have given the concept of purpose a mechanistic formulation in their "drive or motor set" theory. The assumption is that the course of the entire series of acts is guided and controlled with reference to a persistent set (muscular or whatnot) which fulfills the rôle of a goal idea. Hull has advanced a similar theory in his "anticipatory goal reaction" concept and his supplementary concept of "goal gradient."

Tolman insists on a foresight of the goal, or "postulation of a goal position," in all learning. "All learning may be said to involve the representation of the ends of acts at moments before their actual occurrence." Conscious guidance, however vague, is thus assumed to accompany selection and elimination, and direct them.

The difference between this and the Gestalt theory of "insight" is slight. Disregarding minor differences of expression amongst professed Gestalters, the theory seems to imply that there is a tension established within the organism with reference to the problem, which is conceived as a total situation or Gestalt to be responded to. In conscious organisms this amounts to an insight into the meaning of the problem. Hence the Gestalt principle can be thought of as the exact antithesis of the principle of gradual selection and elimination. Unless the new integration is immediate, and unaffected by preliminary trial and error, it is not a case of insight. Aside from presenting some interesting but questionable physical analogies for their hypothetical tensions or stresses, the Gestalt school seem to attempt to answer the problem chiefly by denying it. Maier's work is excepted.

REFERENCES

Alpert, A. The solving of problem situations by pre-school children: an analysis. *T. C. Contr. to Educ.*, 1928, No. 323, p. 69.

Book, W. F. The psychology of skill. New York: Gregg, 1925.

Bryan, W. L., & Harter, N. Studies in the physiology and psychology of the telegraphic language. *Psychol. Rev.*, 1897, 4, 27–53, and 1899, 6, 346–375.

Carr, H. A. Psychology. New York: Longmans, Green, 1925.

Carr, H. A. Principles of selection in animal learning. *Psychol. Rev.*, 1914, 21, 157–165.

Carr, H. A. The reliability of the maze experiment. *J. Comp. Psychol.*, 1926, 6, 85–93.

Culler, A. J. Interference and adaptability. *Arch. Psychol.*, 1912, no. 24.

Dunlap, K. Repetition in the breaking of habits. *Scient. Mo.*, 1930, 30, 66–70.

Franz, S. I. Variation in the distribution of the motor centers. *Psychol. Monog.*, 1915, 19, 80–162.

Goldstein, K. Das Wesen der amnestischen Aphasie. *Schweiz. Arch. f. Neurol. u. Psychiat.*, 1924, 15, 163–175.

Head, H. Aphasia and kindred disorders of speech. New York: Macmillan, 1926.

Hobhouse, L. T. Mind in evolution. New York: Macmillan, 1901.

Holmes, S. J. The evolution of animal intelligence. New York: Holt, 1911.

Hull, C. L. Goal attraction and directing ideas conceived as habit phenomena. *Psychol. Rev.*, 1931, 38, 487–506; 1932, 39, 25–43.

Hunter, W. S. Correlation studies with the maze in rats and humans. *Comp. Psychol. Monog.*, 1922, 1, No. 1, pt. 2.

Hunter, W. S. The delayed reaction in animals and children. *Behav. Monog.*, 1913, 2, 1–86.

Jackson, J. H. Hughlings Jackson on aphasia and kindred affections of speech, together with a complete bibliography of his publications on speech and a reprint of some of the more important papers. *Brain*, 1915, 38, 1–190.

Jennings, H. S. The behavior of the lower organisms. New York: Columbia Univ. Press, 1906.

Köhler, W. Gestalt Psychology. New York: Liveright, 1929.

Köhler, W. The mentality of apes. (Trans. by E. Winter.) New York: Harcourt, Brace, 1925.

Lashley, K. S. Brain mechanisms and intelligence. Chicago: Univ. of Chicago Press, 1929.

Lashley, K. S. The mechanism of vision. I. *Ped. Sem.*, 1930, 37.

Maier, N. R. F., "The effect of Cerebral Destruction on Reasoning and Learning in Rate." J. Comp. Neurol. 193, No. 2, 54, 45–71.

McDougall, W. The nature of inhibitory processes within the nervous system. *Brain*, 1903, 26, 153–191.

Morgan, C. L. Habit and instinct. London and New York: Arnold, 1896.

Perry, R. B. Docility and purposiveness. *Psychol. Rev.*, 1918, 25, 1–20.

Peterson, J. Experiments in rational learning. *Psychol. Rev.*, 1918, 25, 443–467.

Peterson, J. Learning when frequency and recency factors are negative. *J. Exper. Psychol.*, 1922, 5, 270–300.

Peterson, J. Learning when frequency and recency factors are negative and right responses are painful. *Psychol. Bull.*, 1931, 28, 207–208.

Peterson, J. The completeness of response as an explanation principle in learning. *Psychol. Rev.*, 1916, 23, 153–162.

Pyle, W. H. Transfer and interference in card-distributing. *J. Educ. Psychol.*, 1919, 10, 107–110.

Ruger, H. A. The psychology of efficiency. *Arch. Psychol.*, 1910, 2, No. 15.

Smith, S., & Guthrie, E. R. General psychology in terms of behavior. New York: Appleton, 1921.

Ruger, H. A. The psychology of efficiency. *Arch. Psychol.*, 1910, 2, No. 15.

Smith, S., & Guthrie, E. R. General psychology in terms of behavior. New York: Appleton, 1921.

Swift, E. J. The acquisition of skill in typewriting. *Psychol. Bull.*, 1904, 1, 295–305.

Thorndike, E. L. Animal intelligence. New York: Macmillan, 1911.

Thorndike, E. L. Educational psychology, briefer course. New York: Teachers College, 1914.

Thorndike, E. L., & Woodworth, R. S. The influence of improvement in one mental function upon the efficiency of other functions. *Psychol. Rev.*, 1901, 8, 247–261, 384–395, 553–564.

Tolman, E. C. Purpose and cognition: the determiners of animal learning. *Psychol. Rev.*, 1925, 32, 285–297.

Troland, L. T. The fundamentals of human motivation. New York: Van Nostrand, 1928.

Watson, J. B. Behavior: an introduction to comparative psychology. New York: Holt, 1914.

Woodworth, R. S. Dynamic psychology. New York: Columbia Univ. Press, 1922.

Woodworth, R. S. Psychology, a study of mental life. New York: Holt, 1921.

Yerkes, R. M. A new method of studying ideational and allied forms of behavior in man and other animals. *Proc. Nat. Acad. Sci.*, 1916, 2, 631–634.

Yerkes, R. M. The intelligence of earthworms. *J. Animal Behav.*, 1912, 2, 332–352.

CHAPTER X

THE CURVE OF LEARNING

LEARNING CURVE CONSTRUCTION

THE PROCESS of fixation may be studied quantitatively as well as qualitatively. That is, a single criterion of efficiency or excellence in the act may be selected. Progress in learning may then be expressed as the improvement in terms of this criterion from trial to trial.

The learning curve is a graphical device for picturing the *rate* of improvement in terms of a given criterion of efficiency, as a result of practice. It may therefore be said to express the correlation between two variables: effort and achievement. Effort corresponds to amount of practice, and is measured in terms of successive units of practice. These may be trials, or time units, or amount units. Thus practice effort in typing can be measured in terms of the number of successive trials, or the number of successive hours spent in typing, or the number of successive units of typing done, e.g., lines, or pages.

Achievement corresponds to the amount accomplished in each practice unit. This may be measured as time taken to do a given unit of work, or number of errors per unit of work done, or effort necessary to accomplish a given unit of work, or number of units of work done in a given unit of time.

If we let the *ordinate* in Figure 55 represent *units of achievement,* and the *abscissa, units of practice,* or trials, in the accompanying diagram, then it is possible to plot the points representing the level of achievement corresponding to each unit of practice. Thus if, during the first trial, the subject types at the average rate of 20 words per minute, his status at that stage in the learning is properly represented by the point (A). And if, during the second trial he types at the rate of 25 words per minute, his level is now at (B). When a point has been located for each practice unit, then all of these points may be connected by a continuous line to show that they represent stages in a continuous function. The general slope of the line in going from left to right, then, represents the *rate of progress* in learning. Progress or improvement is thus shown to be a continuous function of the correlation between practice and achievement. Hence practice and achievement are *static* loci from which stages of progress can be plotted. They are therefore represented by *points*. Progress, on the other hand, is a *dynamic* process. It is therefore represented by a *continuous line* traveling from left to right.

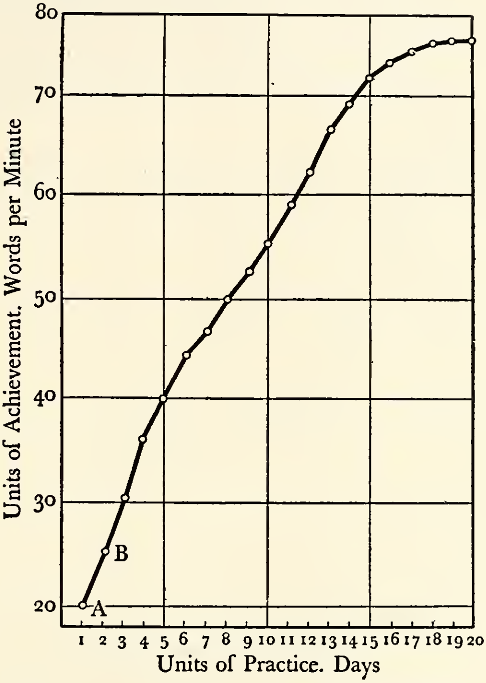


FIG. 55. Practice curve of typing. Illustrating an acquisitive curve of amount

Progress may be variously designated, depending on the units chosen for the two axes. Thus we might have the following typical forms:

(1) *Increase in speed.* This could be expressed as
  (a) Decrease in time necessary per unit of work.
  (b) Increase in amount of work done per unit of time.
(2) *Increase in accuracy.* This could be expressed as

(a) Decrease in number of errors per unit of time or amount done.
(b) Increase in number of units of work or of time per error.

Now since progress or improvement sometimes consists in a decrease in the units, as with time or errors, and sometimes in an increase in the units, as with amount accomplished, it is possible to have either a rising or a dropping curve of learning. The former is called an acquisitive curve, the latter an eliminative curve. Figure 55 illustrates an acquisitive curve of amount, while Figure 56 illustrates an eliminative curve of time plotted on the basis of the same data.

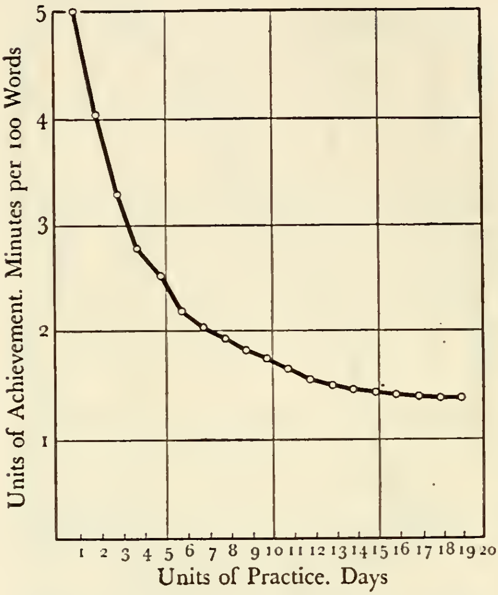


Fig. 56. Practice curve of typing. Illustrating an eliminative curve of time

We are now prepared to consider certain assumptions underlying curve construction. First, the scale units along the abscissa are assumed to express *equal* units of practice, i.e., equal degrees of practice effort. It is very difficult to equate practice units. It is not certain, for example, that, because two practice trials are of equivalent length of time, they therefore represent equivalent amounts of practice effort. The subject might work hard during one and loaf during the other. And, of course, time units and amount units would give quite different results on the same data. For, if time is the criterion, then each successive practice unit will represent a progressively larger work unit, since the more practiced a subject is, the more he accomplishes in the same time. And, conversely, if amount is the criterion, then each successive practice unit will represent a progressively smaller time unit, since the more practiced the subject is the less time he needs to accomplish a given amount.

However, in actual experimental usage, the practice units are assumed to be equal, provided they represent equal units of time, or equal units of amount.

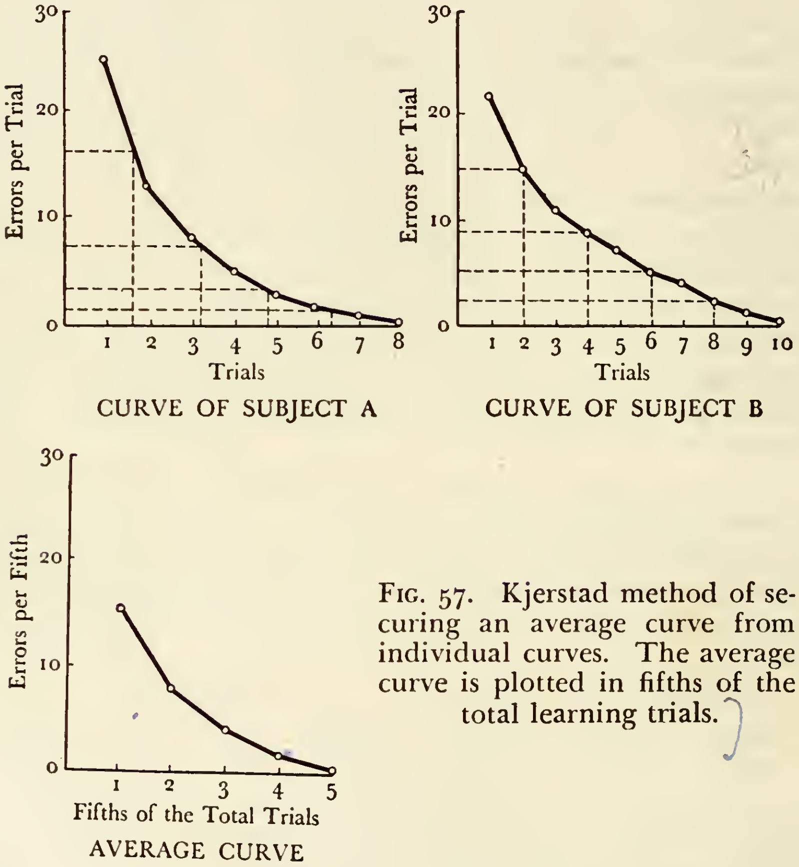
Second, it is assumed that the scale units on the ordinate express equal units of achievement. But this is only true provided certain factors are standardized. First, the zero on the ordinate must be an *absolute zero,* rather than a *relative zero.* For example, suppose the scale units are percentages of the total list of words learned. Then the ordinate zero must represent absolutely no words; otherwise the various percentages represent unequal amounts of learning. Second, the achievement units must represent equal amounts of output, either as to excellence, difficulty, length, or accuracy.

Thus if the unit is a-page-of-typing-written, the material typed must be of homogeneous difficulty, as to speed at which it can be performed, and number of errors likely to be made.

Learning studies do not usually begin at zero learning. The subject has had some practice in the habit previous to the beginning of the study. The shape of the resulting learning curve is radically affected by the *amount* of such previous practice, as will be shown in the discussion of flexions.

Learning curves may express either individual or group results. Group curves are smoother than the individual curves of which they are the combined expression. The reason for this is that all fluctuations which are peculiar to the individual curves tend to cancel out in the average curve. The question is sometimes raised as to which is the truer or more representative, the individual or the average curve. It depends on what is meant by the term 'true.' If all the points on an average curve be compared with those on any individual curve, they will be likely to agree more closely *as a whole* than those of any two individual curves. Yet the individual curves all differ from the average curve in one important respect; they are always irregular. Hence, in this quality, they are the more representative. Yet in showing the general trend or direction of progress, i.e., the learning function, average curves are superior.

The method usually employed for plotting group curves differs from that used in plotting data for a single individual, and is called the "Vincent" method, since it was first employed by her. Obviously if several individuals learn the same habit, they will learn it at varying rates, and each will require a different number of trials. It is necessary to combine these into a single curve. If we merely average the scores on successive trials, the later points on our combined curve will represent averages of only a part of the group, since some will have finished ahead of the others. Vincent



CURVE OF SUBJECT A

CURVE OF SUBJECT B

AVERAGE CURVE

Fig. 57. Kjerstad method of securing an average curve from individual curves. The average curve is plotted in fifths of the total learning trials.

suggested dividing each individual's learning curve into the same number of equal fractions. In this way it is possible to determine what progress each subject made in each given fraction of his total number of learning trials. Let the fraction be a tenth; then ten such values are determined for each subject, and these are then averaged together for all the subjects, giving ten average values which furnish the ten points for the group curve.

Kjerstad suggested a modification of this method in the form of a graphic device, which is more accurate, since it takes care of the excess errors or seconds which by Vincent's method were distributed among the beginning groups. The method is as follows: Every individual curve is accurately drawn on cross section paper. The abscissa is then divided into the required number of equal parts and perpendiculars are erected at these points. The points on the curve where these perpendiculars intersect give the values which are averaged with those of the other subjects to form the combined group curve. See Figure 57.

Where it is desired to eliminate minor irregularities in curves which obscure the general trend, various smoothing techniques are used. Chief among these are: (1) the method of least squares; (2) the method of averaging points; and (3) the free hand method, or the method of observation. Caution should be used in smoothing to insure that the process does not falsify the data. Careful experimenters, if they publish smoothed curves, place the original points in their proper positions, so that the reader may judge of the validity of the smoothed curve.

EMPIRICAL CHARACTERISTICS OF LEARNING CURVES

A STUDY of the results of many kinds of perceptual motor learning has established certain general facts about the learning function. To begin with, it is necessary to distinguish between continuous and discontinuous curves. The former display a consistent trend as a whole, the latter show sudden shifts of trend.

Continuous curves may be negatively accelerated, positively accelerated, or linear. The so-called s-shaped or ogive curve is a combination of the positively and negatively accelerated flexions. Negatively accelerated curves show rapid progress at first, followed by a gradual slowing down in rate of improvement until a stage is reached at which no further progress is apparent and the curve becomes parallel to the abscissa. This stage is known as the asymptote. Theoretically, progress never reaches an absolute standstill, and the curve never becomes absolutely parallel, but practically no further improvement is evident. The curves in Figures 55, 56 and 57 are negatively accelerated.

Positively accelerated curves show slow progress at first, followed by a gradual increase in the rate of improvement, until they are parallel with the ordinate. Practically, however, such curves are rare, and the change in rate of improvement is relatively abrupt. The curve in Figure 58 is positively accelerated. A third possible type of curve is the linear curve, in which the rate of improvement remains constant throughout the learning. The curve is a straight line.

Discontinuous curves are interrupted, as in the case of plateaus, i.e., periods of no progress lasting for some time, followed by a relatively abrupt renewal of progress. Such phenomena are more likely to appear in individual than in group curves, because pauses rarely occur at the same stage in the learning of different persons; the result is that group curves tend to obscure plateaus by averaging.

NEGATIVE ACCELERATION

NEGATIVE acceleration is the most common type of flexion. It presents a variety of forms, depending on the rapidity of change of rate and the rapidity of the original rate of improvement. Many theories have been advanced to explain the function, but, while each theory explains some instances, none is adequate to account for all conditions under which it occurs.

Interference. — It is assumed that as learning goes on and more and more new elements are added, the amount of associative interference amongst elements is multiplied until it finally balances acquisition and progress ceases. This fits situations in which a number of elements are gradually acquired, but not cases of improvement in the performance of a simple act of skill.

Forgetting. — The argument is that forgetting sets in as soon as learning begins, but that it increases rapidly because the more we learn the more we have to forget and an increasing amount of effort must be devoted to relearning or overlearning. A recent biophysical formulation of this theory is in terms of the physics of rate of dissipation of energy.

Motivation. — The initial zest with which the learning is entered upon wanes, and is replaced by a rapidly accumulating ennui. This explanation fits cases in which learning is continuous without rests between. But it hardly explains the negative acceleration obtained in curves of distributed practice.

Order of Selection. — Some investigators argue that the easier units are learned first, while the harder units are left over to the last, thus making the rate of progress decline. Experimental verification of this theory is at hand. But it applies to memorizing, rather than to improvement in simple acts of skill. G. M. Peterson constructed one-syllable-word lists containing sixteen items of unequal difficulty. When these were presented to adult subjects it was found that the easy items were consistently learned first.

Physiological Theories. — These are based on assumptions as to the nature of learning.

(1) The *physiological limit* theory argues by analogy with physical examples that the natural form of approach to a physiological limit is by negative acceleration. Evidence to support this generalization is lacking, and its application to learning is at best an analogy. An objection is that learning curves show asymptotes when no physiological limit is being approached, as in learning nonsense syllables.

(2) *Catalysis.* — An analogy is pointed out between the learning function and the action of a catalytic agent, which is claimed to give a similar function. The agent might be assumed to operate to lower intracellular resistance.

(3) *Psychophysical Function.* — The close resemblance of the learning function to the logarithmic function, which Fechner found to be characteristic of the psychophysical re-

lation, has suggested that these two are manifestations of the same process. If the law of diminishing returns from successive added increments of sensory stimulations applies to sensation, then perhaps it applies also to learning. If $L =$ achievement, or amount learned, and $N =$ number of trials, the formula $s = K \log R$ would then read: $L = K \log N$. This would mean that the amount learned is equal to the logarithm of the number of repetitions times a constant.

POSITIVE ACCELERATION

Exceptions to the general rule of negative acceleration have been reported from time to time. Usually an explanation is to be found in one of the following directions:

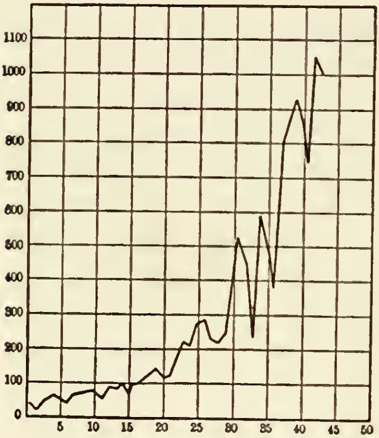


Fig. 58. Swift's ball tossing curve. Each day's practice period continued until ten errors had been made

From *Mind in the Making,* 1908, Chas. Scribner's Sons, p. 174.

Method of Plotting.—The classical example is the Swift ball-tossing curves. He arbitrarily limited the single trial or practice unit in such a way that it was terminated when the subject had made ten errors. His practice units were therefore very short at first, because ten errors were made almost immediately; later they became increasingly long. Theoretically, they might become infinitely long. A success criterion would obviously give a reverse flexion. Peterson has repeated the experiment of ball tossing, using a constant number of catches per trial. Under these conditions the error learning curve is negatively accelerated. Thorndike rearranged Swift's results so that the units on the base line represented equal numbers of tosses and got practically a linear learning curve. Johnson reports a positive acceleration for learning to walk a tight wire, where the criterion of achievement was the number of inches walked, in a given trial, before falling. It is obvious that the shape of a curve is a function of the form of plotting and the sort of data chosen.

Generalization.—Where positive acceleration appears suddenly in the curve it has been attributed to some sort of ideational insight, or seeing into the logic of the situation and arriving at a generalization. For example, Ruger found positive accelerations in his puzzle solving curves. They came usually after a long stretch of trials with slight progress. If such sudden drops in time had been followed by a return to the original rate, they could have been explained by chance, but once they occurred, a new level of achievement was permanently established. What does the suddenness of the drop signify? Does it argue for the Gestalt hypothesis that the corresponding mental integration is sudden and immediate and hence illustrates "Einsicht"? Perhaps. An alternative possibility, however, is that the ideational process accounting for the integration was gradual, and involved trial and error, but that it had no effect on the objective response time until it was complete and hence the sudden drop reflected the initial application of a principle which had been forming gradually in the subject's mind.

Warming Up.—There is no question that warming up occurs in learning performance as in other neuromuscular functioning. Its influence would be in the direction of positively accelerating acquisition. But it is a temporary condition within the continuous trial and would disappear between trials separated by a few hours or more. Its presence, therefore, would only explain positive acceleration in massed learning.

PLATEAUS

Bryan and Harter in their study of the acquisition of telegraphy first reported plateaus. These are defined as periods of no progress of some duration, followed by a relatively sudden resumption of progress. They appeared in the curve of the receiver but not in that of the sender. Both Swift and Book report plateaus in learning to typewrite, and others have corroborated their findings. Batson found them in the learning curves for complicated ball throwing. On the other hand, many learning curves of simple functions lack even plateaus of short duration. Several explanations have been advanced, of which the following are important:

Bryan and Harter offer a theory of hierarchies of habit. In the case of a complex habit like telegraphy, learning involves the building of higher order units on simpler units as a foundation. Thus receiving of words requires a thorough perfection of letter habits, and sentence receiving requires highly integrated word habits. It is the delay which must occur, for example, after the word habit has been learned, while it is being brought to a high degree of automatization, before the sentence habit can appear, that accounts for the plateau. Swift advances a similar theory of automatization of associations during the plateau period. He accounts for the sudden resumption of progress in this way.

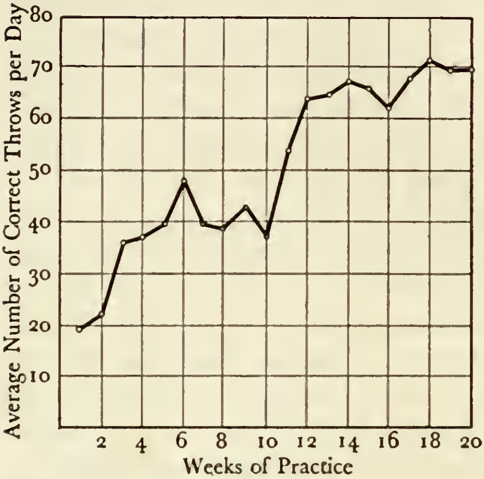


FIG. 59. Plateau curve from Batson's data for subject "M," averaged by weeks. The plateau extends from the third to the tenth week

Psychol. Monog., 1916, 21, p. 92, Plate 5.

The Constant Obstacle. — Book explains the plateaus in his typewriting curves as due to slumps in attention and interest caused by the multiplication of obstacles at a certain stage in learning. These points are assumed to be relatively constant. The weakness in the theory is that with such large individual differences in rates of learning and kinds of difficulty there should be no *constant* point for the plateau, and average curves should not show it. It is assumed that, with time, the interfering factors are weakened and drop out.

Both Book and Swift have suggested that, in a complex process, a shift of emphasis from one aspect of the process to another would cause plateaus. Thus if attention is first devoted to accuracy and then shifted to speed, the curve of speed would show a sudden jump at this point. A similar result would be produced where a subject abandoned one method of attack, and adopted a different one.

Multiple Learning Curve. — The very fact that plateaus are associated with complex and not with simple learning functions suggests the following theory: As soon as one part of a complex problem has been brought to perfection, at which time the curve will have reached an asymptote, the subject attacks some other aspect, and a new learning curve is initiated. In very complex problems there should be not one but several plateaus marking the points of shift of attack. To test this theory, Batson experimented with three types of motor problems: one in which an isolated factor was operating, as force of throw, or timing, or direction alone; one in which a number of factors were working *simultaneously,* as in ball tossing, where force and direction of throw and timing of catch all enter; and one in which several factors were working *successively,* not simultaneously. Only the last type of problem produced plateaus. The second type did not give plateaus even when the subject was instructed to try to attend to the features separately, for improvement in all of them progressed simultaneously.

OGIVE CURVES

Evidence is accumulating to show that under certain conditions the learning curve is S-shaped or ogive in appearance. The early stages of the curve show positive acceleration which is followed by negative acceleration and an eventual asymptote. What are the conditions requisite for the appearance of this double flexion in the curve? One theory, suggested by Culler, who obtained such a curve, in establishing a conditioned response in a dog, is that the S-shape is the typical shape of the learning function for habits which have received no previous practice of any sort. Such acts are necessarily rare, because most acts are benefited by previous practice in the part processes involved. Thus learning to draw is benefited by having learned to use the same muscles in writing. Therefore the presumption is that in the traditional negatively accelerated curve, the initial positive flexion has taken place before formal practice is begun. Thurstone, in a recent article suggesting a rationalization of the learning function in terms of the probable rate at which errors will be eliminated and correct acts fixated at different stages of the learning process, argues that all learning curves are S-shaped, but that the flexion point may occur very early when the task is heterogeneous.

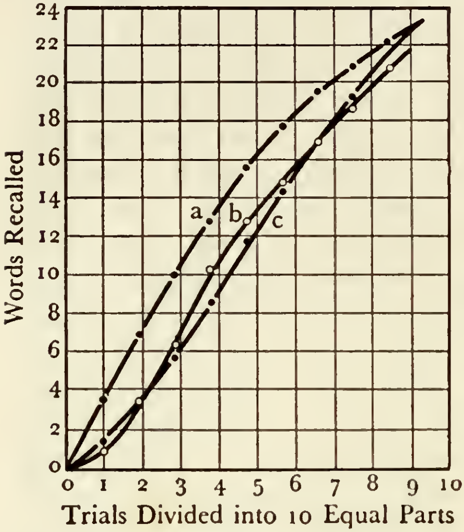


Fig. 60. Learning curves for material of three different degrees of complexity. In curve *a*, the monosyllabic nouns were taken singly, in curve *b*, they were taken two at a time, and in curve *c*, they were taken three at a time

From Stroud, Amer. Jl. Psychol., 1932, 44, p. 729, Fig. 5.

Stroud obtained S-shaped curves in the learning of monosyllabic words, where the task was made complex by combining two words into each unit to be learned. When three words were used in each unit a positively accelerated curve resulted. See Figure 60. Complexity, then, may be a factor.

Minor Fluctuations

The individual learning curve differs characteristically from the group curve in showing wide temporary fluctuations. The assumption is usually made that these are due to chance — i.e., to a number of minor uncontrolled variables whose action is sporadic and hence does not affect the general trend of the curve. There is a possibility, however, that, where the learning is massed into a continuous stretch of time with no rests between, these fluctuations are significant. They may result from some physiological rhythm expressive of recurrent refractory period, or some other fatigue phenomenon, affecting the continuity of attention. Wheeler publishes curves of continuous practice on blindfold maze tracing, over two hours, when the repetitions followed one another so rapidly that the subject could not relax. His curves show a characteristic wave formation with troughs occurring about every forty runs.

THE LEARNING CURVE EQUATION

THE problem of discovering an equation which would describe the typical learning curve function was undertaken first by Thurstone. He performed the preliminary task of fitting several equations to the curve with the idea of securing an empirical fit. After experimenting with forty different equations on published learning data, he selected an empirical equation, which is a form of the hyperbola. For learning curves which pass through their origin, i.e., start at zero practice, the equation is:

$$Y = \frac{L \cdot X}{X + R}$$

in which

Y = *attainment* in terms of the number of successful acts per unit time.
X = *formal practice* in terms of the total number of practice acts since the beginning of formal practice.
L = limit of practice in terms of attainment units.
R = rate of learning.

In many curves, practice has preceded the beginning of the curve so that the curve does not pass through its origin. In these cases the following corrected equation is suggested:

$$Y = \frac{L(X + P)}{(X + P) + R}$$

in which P = *equivalent previous practice.*

On the basis of this, he proposed to predict both the limits of practice and the further course of the function in incompleted curves, as well as to reconstruct the early stages of a curve whose later course is known, e.g., in cases where the subject is already partially practiced in the function. Thurstone's hyperbolic equation has been verified for curves of practice in mental multiplication by Barlow. An empirical equation, however, has no more than a descriptive function.

A rational equation, on the other hand, based on a consideration of some rational explanation of the form of the learning function, would offer a step in advance. But the acceptance of any rational equation of the learning function necessitates acceptance of a number of assumptions about the nature of learning which the author of the rational equation has made. The first rational equation was suggested by Meyer. He first defined the variables and constants which he assumed were involved and then wrote an equation on the basis of these. His assumptions regarding learning are rather unique. Recently Thurstone suggested a rational equation for rote learning, based on simpler assumptions. For homogeneous learning tasks, he postulates an S-shaped learning curve which satisfies the rational equation

$$\frac{2p - 1}{\sqrt{p - p^2}} = \frac{kt}{\sqrt{m}} + z_0$$

in which p equals proportion of successful acts in unit time; t equals the practice time; k the subject's learning constant, meaning the average number of errors eliminated in each exposure; m equals the complexity of the task; and z_0 may be regarded as a constant. (It is the value of z when p equals p_0 and p_0 is the value of p when t equals zero.) From this, Thurstone argues that a homogeneous learning task will have an inflection point at p equals .5, or midway; while a heterogeneous task will give a nonsymmetrical curve with inflection point in the lower half. Very heterogeneous tasks will fail to show the inflection point. If two different levels of complexity are involved, the curve will show a plateau, due to the perfection of the simple part first.

MEMORY

Studies of memory constitute a large proportion of the work on learning. It has been pointed out that the distinction between perceptual motor learning and memory is arbitrary, since the use of symbolic representatives is not confined to verbal and informational recall nor is the reinstatement of actual movements confined to the revival of acts of skill. Yet for practical purposes the type of learning involved in remembering facts is distinguished from that involved in acquiring skills. Experiments in the field of memory have stressed different features and used different techniques.

Forms of the Memory Function

Experimental studies of memory have divided the total function into three main phases: (1) *Fixation,* or the original process of acquisition; (2) *Retention,* during the period between fixation and later use; and (3) *Reinstatement.* The last of these includes recall, and all other forms of revival. Woodworth adds to these a fourth phase which he considers unique, i.e., *recognition.* But it seems logical to consider recognition a special form of partial or incomplete revival.

There is striking evidence for the functional independence of these four phases of memory in certain findings of pathology. Thus subjects may show *amnesia of fixation,* so that new impressions are received with great difficulty, and yet possess unimpaired retentive capacity for past impressions and good recall. Or they may have *amnesia of retention* with the others intact. A blow on the head or other physical or emotional trauma will cause the dropping out of large segments of experience from memory. When the cause is brain deterioration from disease or old age, the impressions of early childhood are retained longest, and disappear last. Finally, there may be *amnesia of recall,* with fixation and retention intact. Thus a subject usually is unable afterward to recall what occurred to him while in a hypnotic trance, particularly if the operator was careful to suggest post-hypnotic amnesia during the trance. Yet, in a later trance, the subject can be induced to recall what took place in the former one. This shows that the impressions were *retained,* but were not *recalled* under the waking condition. Emotional embarrassment, shock, and distraction have a similar effect on recall.

Studies of Memory: Materials and Methods

Materials. — The systematic experimental study of memory was begun by Ebbinghaus in 1879. He initiated the use of typical sorts of material, as nonsense syllables, as well as special methods of presentation. Among the materials commonly used are passages of prose, passages of poetry, lists of disconnected words, nonsense syllables, numbers, geometrical forms, pictures, etc. There are certain advantages and disadvantages in their use, depending on the nature of the problem. For experimental purposes, material should be (1) relatively uniform and easily devisable, so that several units of equivalent difficulty may be selected. Only in this way can a high reliability be expected from task to task; (2) Its association value should be equivalent for different individuals, so that one subject is not favored over another; (3) Provided pure rote memory is being investigated, and it is desired to eliminate logical and meaningful relations, nonsense material is best; (4) But if the operation of associative aids is to be studied the material should represent all degrees and kinds of meaningfulness. Ebbinghaus invented the nonsense syllable to avoid individual differences in associative value. According to present usage a nonsense syllable consists of three letters — two consonants with a vowel between. There are 1100 of these available in English. The assumption of Ebbinghaus that nonsense syllables yield a higher reliability than words in learning, from list to list, and individual to individual, has been tested by Carr, Davis, and Sauer. Davis found that nonsense syllables have the greater absolute variability, and the greater relative variability previous to practice; though after practice they are relatively less variable. Sauer found that, from individual to individual, words are the more variable of the two.

Methods of presenting materials

A memory experiment always consists of the systematic presentation of the material to be learned followed by tests of the efficiency of the learning. The material may be presented all at once or serially in parts. It may be learned in one exposure or in several. All may be learned or only that part which can be acquired within a limited time. The following methods are used:

(1) *The complete exposure method.*—In the learning of connected poetry or prose, the entire passage may be placed before the subject and he may study it in any order he chooses.

(2) *The serial exposure method.*—Nonsense syllables, numbers and detached words, are usually arranged in lists, and presented serially, one at a time, each one being exposed for an equal time, e.g., three seconds. Thus learning time per item is standardized; each total presentation of the list takes a constant time, and total learning time can be measured by number of presentations.

(3) *The anticipation method.*—This is a form of serial exposure. The list of items is first presented serially once. Then, on the second presentation, as each item appears, the subject anticipates the next one to be exposed, by pronouncing it before it appears. A given time, say three seconds, is allowed for the recall of each item. A record is kept of the number correctly anticipated on each successive presentation of the list, until all have been correctly anticipated, when the list is considered learned. This method tends to produce vertical associations.

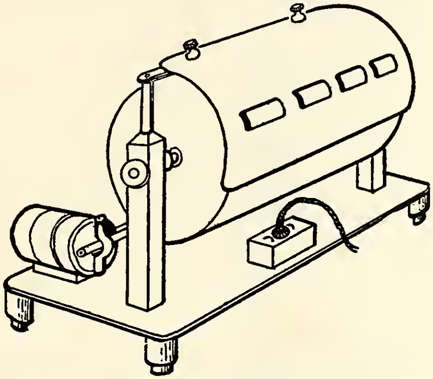


FIG. 61. Automatic memory drum

(4) *The prompting method.*—This is exactly like the preceding, with the addition that the experimenter records the number of promptings and corrections given. Usually, in the anticipation method prompting consists in the check which the subject has on his recitation of each item, when that item appears to view.

(5) *The paired associate method.*—This is another type of serial exposure in which each item in the list consists of two terms, side by side, which are to be associated horizontally. After each exposure of the entire list, a special test series is run in which the left hand member of each pair is exposed and the subject is asked to recite the right hand member. Learning is considered complete when the test series is 100% correct. Learning time is measured by number of presentations. Often the items are scrambled before each test, to discourage vertical associations and compel horizontal ones.

Anticipation Method	Paired Associate Method
JAT	FUG —— DOJ
/	
HEZ	VEC —— ZAN
/	
QUN	PID —— NUQ
/	
DAZ	GOZ —— JID
/	
SOG	QUD —— FOS
/	
TEQ	ZEH —— PEF
/	
NUP	YAT —— XIB
/	
ZOF	MUV —— VUS

The dashes show the direction in which associations are formed in the two cases; the former method producing vertical, the latter method horizontal bonds.

(6) *Memory span.*—According to this method only enough material is presented so that the subject can learn it in one short exposure. Memory span is measured by the amount an individual can assimilate in a single exposure. Of course this differs with the time allowed, which varies all the way from 1/5 second to a minute or more.

(7) *The partial learning method.*—When Ballard had school boys learn ballads he allowed them a constant period of time for the learning. He then tested them to find what proportion of the total ballad they had learned. When this

is applied to lists of items it is called the *Method of Retained Members.* To be objective it should be used with material in which the units are of equal difficulty. Then the subject can be credited a given amount for each item correctly reproduced and an extra amount for each item given in its proper order.

(8) *Sense avenue.*—Presentation of material may be visual or auditory or both. If several items are to be presented, this can be done simultaneously through vision but must be done successively if auditory presentation is used. Hence visual memory span and auditory memory span are different things.

Methods of scoring and measures of retention

Methods of studying learning differ in terms of the measures of success employed. More will be said about these in connection with the discussion of the topic—Retention.

The following forms are used:

(1) Recall or oral reproduction of the items.

(2) Written reproduction.

(3) The *saving* method, or the ratio of number of repetitions to relearn the material to number of repetitions necessary to learn it in the first place.

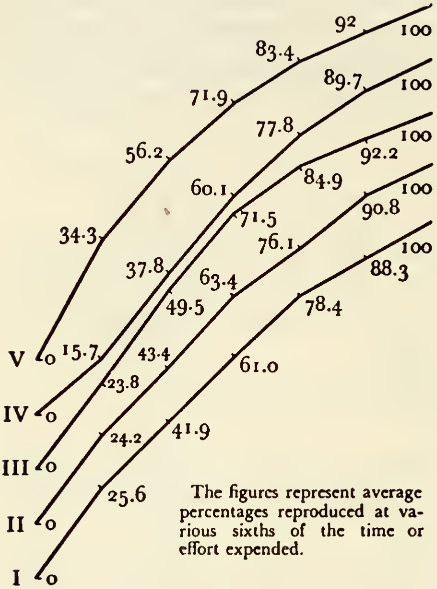
(4) Recognition, or the ability to recognize the items learned, when they are presented in a list of mixed items, half of which are new, and have never been seen before.

To score the recognition properly, since guesses of right or wrong will be 50% correct by chance, it is necessary to compute twice the number of errors, add to this the number of cases in which no answer can be given, in order to get a measure of the cases in which memory has failed. The final score is then obtained by subtracting this from the total number of items, new and old, exposed in the test series.

(5) Reconstruction. The subject is presented with the stimuli in a given order for learning. They are then exposed in a scrambled order for the test series and he is directed to reconstruct the original order.

THE CURVE OF MEMORIZING

If there is no essential distinction between memorizing and other forms of the learning function, we should expect to find the curve of memorizing resemble that for acts of skill. Certain differences ought to appear, however. One is the manner in which the limit of learning is approached. Since, in memorizing lists, there are a limited number of items in the list, progress is abruptly terminated at the point at which all the items can just be recalled. Theoretically, overlearning would improve the function, but there is no way of showing this in the objective curve. Hence we should expect the limit to be approached rather abruptly, instead of with a gradual asymptotic flexion.



The figures represent average percentages reproduced at various sixths of the time or effort expended.

V = Serial Nonsense Material - 12 syllables
IV = Paired Nonsense Material - 12 pairs
III = Meaning Material - 18 ,,
II = Number-Syllable Material - 12 ,,
I = ,, ,, ,, - 9 ,,

Fig. 62. Curves of memorizing

From Kjerstad in Psychol. Monog., 1919, 26, No. 5, p. 82, plate 5.

Another difference might result from the fact that memorial learning is usually massed into a single continuous practice session, so that fatigue, warming up and other temporary functions can enter into the determination of the curve.

To obtain curves of memorizing, a method of learning must be used which yields a recall score at the end of each trial or presentation; either the anticipation or the complete recall method accomplishes this.

Kjerstad published the pioneer study of the curve of memory. He studied four different types of material, serial nonsense material, paired nonsense material, meaningful words, and number-syllable combinations. All the curves were plotted on a comparable basis, regardless of absolute length of learning time, by dividing them into sixths and plotting the amount learned in each sixth at equal distances with reference to the abscissa. This is a modification of the Vincent technique, previously described. The resulting curves, appearing in Figure 62, show certain differences. The serial nonsense material and the number-syllable combinations show the typical negative acceleration, though the upper limit is reached abruptly. But the paired nonsense syllables show the ogive shape, i.e., an initial positive acceleration followed by a negative acceleration. Stroud's results on word combinations, in which the more complex units yielded ogive curves, are relevant. Kjerstad found that other factors, as length of list, practice, exposure time, and number of presentations, do not have any influence on the general form of the curve. A characteristic reported by White is the ' final spurt ' or the tendency for greater progress to occur in the final presentation than in the immediately preceding ones.

MEMORY SPAN

The memory span experiments form a unique topic distinct from other memory studies. The memory span is defined as the largest quantity of material that can be correctly reproduced after a single presentation. The average memory span for unrelated items is 7 to 8. But it is influenced by the arrangement of the stimuli, their meaningfulness, and the sense avenue through which they are presented. Individuals differ in their memory span, depending upon their age, sex, and intelligence. Practice has some effect in increasing the size of the span.

FORMS OF ASSOCIATION IN MEMORIZING

A study of memorial learning brings out the typical kinds of associations formed. Items in lists are connected serially; each item is associated with its position in the series; each is also integrated with the list as a whole. Ebbinghaus demonstrated that associations are formed both backward and forward, between terms but that the forward associations are much stronger. That this is in part a matter of the experimental set of the learner has been shown by Cason. Subjects report the use of accessory aids, such as ready formed associations, relationships observed within the material, key items used as foci for attention, forced groupings of the material and superimposed patterns. Such individual differences occur that it is impossible to formulate any general rules. Previous to practice, subjects try out various schemes. After practice they tend to fall back upon rote memory, and casual association.

REFERENCES

Ballard, P. B. Obliviscence and reminiscence. *Brit. J. Psychol. Monog. Suppl.*, 1913, 1, No. 2.

Barlow, M. C. A learning curve equation as fitted to learning records. *Psychol. Rev.*, 1928, 35, 142–160.

Batson, W. H. The acquisition of skill. *Psychol. Monog.*, 1916, 21, pp. 92.

Book, W. F. The psychology of skill. New York: Gregg, 1925.

Bryan, W. L., and Harter, N. Studies in the physiology and psychology of the telegraphic language. *Psychol. Rev.*, 1897, 4, 27–53, and 1899, 6, 346–375.

Cason, H. Specific serial learning; A study of remote forward association. *J. Exper. Psychol.*, 1926, 9, 299–324.

Cason, H. Specific serial learning; A study of backward association. *J. Exper. Psychol.*, 1926, 9, 195–227.

Culler, E. A. Nature of the learning curve. *Psychol. Bull.*, 1928, 25, 143–144.

Davis, F. C. The relative reliability of words and nonsense syllables as learning material. *J. Exper. Psychol.*, 1930, 13, 221–234.

Ebbinghaus, H. Memory. (Trans. by Ruger and Bussenius.) New York: Teach. Coll., Columbia Univ., 1913.

Johnson, G. B. A study in learning to walk the tight wire. *Ped. Sem.*, 1927, 34, 118–128.

Kjerstad, C. L. The form of the learning curves for memory. *Psychol. Monog.*, 1919, 26. Pp. 89.

Meyer, M. F. The equation of the learning function. *Amer. J. Psychol.*, 1923, 34, 203–222.

Peterson, G. M., Negative acceleration with material of varying difficulty. *J. Exper. Psychol.*, 1928, 11, 40–44.

Peterson, J. Experiments in ball-tossing: the significance of learning curves. *J. Exper. Psychol.*, 1917, 2, 178–224.

Ruger, H. A. The psychology of efficiency. *Arch. Psychol.*, 1910, 2, No. 15.

Sauer, F. M. The relative variability of nonsense syllables and words. *J. Exper. Psychol.*, 1930, 13, 235–246.

Stroud, J. B. Effect of complexity of material upon the form of learning curves. *Amer. J. Psychol.*, 1932, 44, 721–731.

Swift, E. J. The acquisition of skill in typewriting. *Psychol. Bull.*, 1904, 1, 295–305.

Swift, E. J. Studies in the psychology and physiology of learning. *Amer. J. Psychol.*, 1903, 14, 201–251.

Thorndike, E. L. Educational psychology. Vol. II: The psychology of learning. New York: Teachers College, 1913.

Thurstone, L. L. The learning curve equation. *Psychol. Monog.*, 1919, 26, No. 114, Pp. 51.

Thurstone, L. L. The learning function. *J. Gen. Psychol.*, 1930, 3, 469–493.

Vincent, S. B. The function of the vibrissae in the behavior of the white rat. *Behav. Monog.*, 1912, 1, No. 5.

Wheeler, R. H. The science of psychology. New York: Crowell, 1929.

White, G. C. The form of the curve of memorizing. *J. Exper. Psychol.*, 1932, 15, 184–194.

Woodworth, R. S. Psychology. A study of mental life. New York: Holt, 1921.

CHAPTER XI

FACTORS INFLUENCING THE EFFICIENCY OF LEARNING

A CAREFUL study has been made of a large range of factors which directly influence the economy with which learning takes place. Among the more important of these are: (1) the distribution of effort; (2) the kind and amount of material presented; (3) the methods of presentation; (4) the attentive and volitional attitude of the subject; (5) the motives and incentives operating; (6) the amount and forms of guidance or tuition introduced; (7) the organic condition of the subject; and (8) the effect of individual differences in age, sex, and intelligence. The experimental work on each of these special topics will be summarized in the following pages.

DISTRIBUTION OF EFFORT

MORE attention has been devoted to the various aspects of this problem than to any other. The chief questions investigated center about the topics of (a) distribution of trials and (b) the whole and part methods of attack.

Distribution of Trials

In general, the interpolation of intervals of time between practice periods has been shown to be beneficial, whether in memorizing or in acquiring skills, by a host of experimenters. This generalization might be called the Law of Distributed Practice. But the problem is complicated by several considerations. To begin with, it is possible to hold the length of the individual practice periods constant, and vary the length of the rest periods between. Or the length of the practice periods may be systematically varied, while the intervening rest periods are held constant in length and varied in frequency. Or both practice periods and rests can be varied concomitantly. Again, the stage of learning at which the rests are introduced can be varied, so that they are concentrated in the early or late stage; or they may be merely more frequent in the early learning and rarer later. A related problem is the influence on retention of overlearning beyond the point of just perfect reproduction, and the benefit of occasional reviews after practice has ceased. These last questions will be discussed later under Retention.

Ruch has pointed out the differences which result from differences in the kind of materials used by different experimenters. These range from nonsense materials, used by Ebbinghaus, Lyon, Jost, and Robinson, and meaningful verbal and numerical materials used by Lyon, Gordon, Thorndike and Cummins, to human motor habits, such as the stylus maze by Carr, Pechstein, Culler, Hardy and McClatchy; typewriting by Pyle, and target practice by Lashley.

Length of Interval between Trials.—Ebbinghaus found that 68 concentrated repetitions of nonsense syllable lists gave less learning than thirty-eight repetitions distributed over three practice periods with a day between each. Jost confirmed the superiority of the latter method even when the subject was artificially fatigued before each of the distributed practice periods. But on connected prose and poetry, Lyon found no such advantage. Robinson found an advantage in dividing twelve presentations of a list of three-place numbers into two sets of six readings each, separated by 24 hours. But no advantage appeared when six presentations of similar lists were divided into two sets of three readings each, separated by 24 hours. He tested recall after five minutes, twenty minutes, and twenty-four hours. Since the divided practice worked best for the 24-hour recall, he concluded that the amount of advantage of a rest interval in learning depends on how soon recall is tested. Elaborate investigations of the *optimal* interval between trials have been made by Warden for animal, and Hardy for human maze learning. Warden, using a square maze with rats, tried rest intervals of 6 hours, 12 hours, 1 day, three days, and five days. He also tried the effect of interpolating the rest after each trial, each three trials and each five trials. According to the criterion of total trials to learn, the twelve-hour interval was best under all conditions. Six hours and one day were next, and the periods beyond a day gave progressively poorer learning. Hardy, working with human subjects, on a stylus maze, duplicated Warden's experiment. She found, for her three-trial group, that the one-day interval was poorest, the twelve-hour and two-day intervals were next, and the periods beyond two days gave progressively better results, with the optimum at her longest interval, i.e., four days. These results are the direct reverse of Warden's and compel the assumption that the optimum interval is a function of the kind of organism. Hardy's results on the maze agree closely with Perkins' for nonsense syllable learning.

Length of Practice Period.—Perkins corroborated Ebbinghaus' and Jost's finding that, when a constant rest interval was introduced after one, two, four, and eight repetitions of a list of nonsense syllables, the most frequent rests gave the optimal effect. She found that variations in length of rest between one and four days failed to change the relation. Lashley found that five trials a day was superior to twenty, forty or sixty in practicing archery. In animal work, a long list of experimenters, including Ulrich, Lashley, Brockbank, Yerkes, Hunter, and Warden, have reported that one or two trials a day are superior to any greater number in the learning of mazes. But in human maze learning Hardy found no relation between speed of learning and number of trials per practice period, and Culler found when he inserted a day's rest after one, two, three, four, six, and twelve trials, on the stylus maze, that the longer practice periods were superior.

Meaningful material gives different results from nonsense material. Lyon carried out experiments on learning prose and poetry, to parallel those on nonsense syllables, and found no advantage for distributed practice here.

Delayed recall profits more by distributed practice than immediate recall. Austin found that five concentrated readings of logical material were as good as one per day for five days, when tested by immediate recall; but, with recall after two weeks, the divided practice was three times as effective. Robinson's experiment on three-place numbers, and Gordon's on connected prose corroborate Austin.

Stage at Which Rest Is Interpolated.—There is no a priori argument for distributing the rest intervals uniformly throughout the learning process. In fact, there is reason to suppose that divided effort would be of greatest advantage during the early stages of learning, during the exploratory period, and that concentrated practice during the later fixation period would be best. Carr compared the two conditions of stylus maze learning, one in which the first ten trials were massed, and the last ten separated; and the other in which the separations occurred in the first ten trials, with massing later. He found the latter condition superior. But Lashley found distribution more important in the later stages of practice in archery. McClatchy discovered that the optimal position for interpolating a rest period depended on its length. A 48 hour rest was best introduced after the seventh trial; for a 24 hour rest, the favorable position was between the first and fourth trials.

Cummins introduced a new feature into the problem by comparing a gradually decreasing length of practice period as learning progresses with a gradually increasing one. The results are in favor of massing of effort during the initial stages of learning, where the material is school subjects.

In explanation of the apparent conflicting evidence on distribution of effort, it should be pointed out that no two experimenters used exactly the same conditions and that discrepancies can be explained in terms of differences of subjects, materials worked with, criterion of learning, and methods of presentation, and the nature of the subjects' activities during the rest interval.

Theories Regarding Distributed Effort

That some distribution of effort in learning is advantageous, seems established beyond question. But any adequate theory to account for the fact must apply to all the different conditions on which there is experimental evidence, provided it is given universal explanatory significance. Thus, such theories as that of memory review during the rest period could not apply to animal subjects, and the theory of loss of interest and attention could not explain the advantage of rest after very short trials. The fatigue theory advanced by Müller cannot be universally applicable for the same reason, and the experiment of Jost, previously referred to, disproves it. Lashley's conclusion, that the benefit of rest intervals is due to incidental factors arising from the particular conditions of each study, should not be resorted to except as a final gesture of defeat. Warden points out the significance of an optimal length for the rest — that it may be either too short or too long. He therefore favors a modification of the perseverative theory, which assumes that a "setting in" process takes place subsequent to practice in a function, during which neurochemical changes are occurring which are essential to fixation. Any activity engaged in immediately subsequent to the practice period would interfere with this fixation process; hence a rest period is beneficial. However, if the rest is too long, forgetting sets in to reverse the effect. This is an extremely plausible theory, but there are serious objections, the discussion of which must be left to the chapter on Retention.

At least one other possible explanation is that of the dropping out of conflicting habits during rest. This view was advanced by Book and by Swift to account for the extremely rapid improvement in practiced habits when practice is again resumed after a rest period of over a year. Book found that, after a few minutes of warming up, the average speed of students in typing showed a gain of 6% over their best previous speed as a result of a year and a half of rest. And Swift found after a twenty month rest from practice in ball tossing, increases in scores from 1051 to 1187 and from 1268 to 1519.

Mention should be made of Jost's law to the effect that, in memory, practice is more effective on older associations. Given two associations of equal strength, but unequal age, repetition will be most effective on the oldest one. It is possible that Book's and Swift's results are of this sort.

The pertinent question as to the effect of the kind of activities engaged in during the rest interval upon the value of the rest will be answered in discussing retention.

Whole and Part Learning Methods

In connection with the problem of distribution of trials in learning, the question arises — Is it economical to split up *connected* material? Should material be learned as a whole, or in convenient parts?

Obviously, many factors complicate the problem, such as the absolute size of the whole, the nature of the material, the number and kind of parts into which it is divided, the age and intelligence and previous method of learning of the subjects.

The consensus of opinion of earlier investigators favored the whole method. Steffens (in 1900) investigated the efficiency of the whole method as compared with the natural and part methods and the combined part-whole method, in learning poetry, prose, and syllables. The "natural" method, adopted by the subjects themselves consisted of repetition by parts, interspersed with reading as a whole. Steffens' results lack general significance, since her separate studies were each performed on a single subject, but enough measures were taken to make the results reliable for the individual. The whole proved slightly superior to the natural method for poetry, but not unambiguously so for syllables. An experiment in which stanzas of eight lines of poetry were learned as a whole, and in two equal parts, showed the whole method superior. Prose passages of four lines were learned better by the whole method, but this superiority disappeared with eight-line passages. Lists of twelve syllables were learned more rapidly as a whole, than when each half was repeated eight times before uniting. A combination of the whole and part methods proved practically as efficient as the pure whole method.

Lakenan demonstrated the superiority of the whole method for both prose and poetry, where one line of poetry or one sentence of prose constituted the part unit. The superiority was evident also in retention after one year. The longer the passage, the greater the advantage of the whole method. Thus, for a nine-line passage of poetry, the whole method gave 8% superiority for learning and 12% for retention after two to seven months; while for a thirty-six line passage, it gave 32% superiority for learning and 22% for retention. Pyle and Snyder confirmed her finding for lengths up to 240 lines, where the part method consisted of breaking the passage into halves, thirds, fourths, or fifths. Earlier German investigations favoring the whole method in general are those of Ebert and Meumann, Ephrussi, Neumann, and Pentschew. And recently Warner Brown has found it superior in learning vocabularies; R. W. Brown, in learning musical scores on the piano; and Crafts, in card sorting.

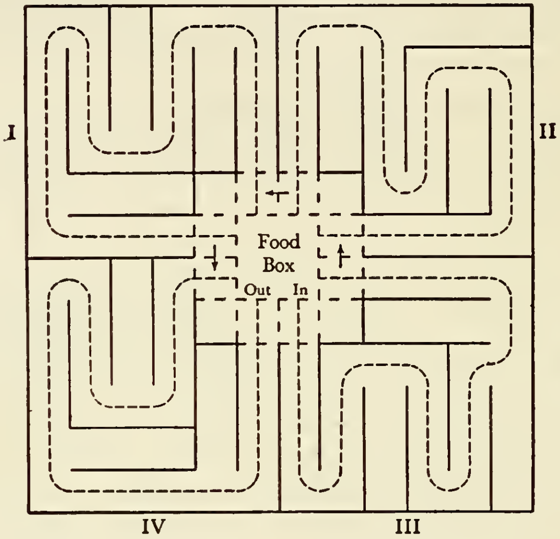


Fig. 63. Pechstein's maze for progressive part learning

From Psychol. Monog., 1917, 23, No. 2, p. 70, Fig. 1.

On the other hand, an imposing mass of evidence supports the part method in one form or another. Pechstein made a comparative study of animal and human maze learning. He used a combination maze consisting of four parts which could be isolated or joined by closing or opening partitions. He compared (1) the whole method, i.e., running the entire four parts in succession each trial, with (2) the pure part method, i.e., learning the four parts separately, and (3) the progressive part method, in which the first part was learned, then the second, then the first and second together, then the third, then the first, second and third together, etc. For both animals and humans the progressive part method was superior. Recently Barton studied the effect of splitting up a single stylus maze into parts and repeating each part until learned. He found this method markedly superior to learning as a whole. Pechstein, after a careful consideration of the basis for the superiority of the progressive part method concludes that learning by parts has the advantage of shortening a complex task to a size commensurate with the subject's ability, but the disadvantage of setting up position habits, which must be broken up again when the parts are united. The progressive part method corrects this disadvantage, and hence is superior.

Pechstein demonstrated also that the part-whole problem is bound up with the problem of massed versus distributed learning. Thus if a complex problem is split up and learned by parts, it is best to learn both the units and connections under massed conditions. If distributed learning is used, the whole method suffers least. Recent confirmations of Pechstein's results on other motor problems are offered by Koch, for simultaneous right- and left-hand performance in typewriting, and by Gopalaswami for mirror tracing.

Reed, by attacking the too ready acceptance by psychologists of the superiority of the whole method, re-awakened interest in the problem. In three experiments of his own, 169 college students were tested on logically connected prose and 226 on poetry by the part, whole and part progressive method. The majority favored the part progressive method and found the whole method poorest of all. Yet a sizable minority preferred the whole method, showing that individuals differ. Reed's results may be considered quite significant. The fact that the part method required breaking up the meaning of the prose passage makes its superiority doubly striking. Reed points out that the early studies of Meumann and Pentschew should be interpreted as favoring the part method in so far as economy is measured by learning time; and that those of Ephrussi and Pentschew prove its superiority for nonsense syllables and vocabulary. He concludes that the part method gains its superiority by adjusting the material more adequately to the learner's span of attention.

Winch divided 38 eleven-year-old school children into two groups, one of which learned poems a line at a time, the other learned them as a whole. The part method gave more economical results, in some cases as high as 52%, and was advantageous for short or disjointed materials.

Two phases of the problem have recently received special treatment. The results of pioneer investigators had suggested that the age and intelligence of the subject determined which method would be superior, and had proved the part method more economical for young and less intelligent subjects. Pechstein compared eighth grade children of high and dull normal level on whole and part poetry learning; he found the advantage of the part technique much greater for the dull group. McGeoch found the whole method superior for learning and retention of vocabulary with both normal and gifted children, but its advantage was much greater for the gifted. On the other hand, neither method proved superior in the acquisition of poetry.

The other point concerns previous habits. Most persons learn habitually by the part method. McGeoch found that not one of her group of 30 subjects naturally used the whole technique. It is possible that, with equal practice in each method, those who initially favor the part would eventually prefer the whole method. Wylie, using 162 college students, equated the practice factor, by alternating the two methods from day to day over a period of five weeks. Under these conditions, the whole method nearly always proved superior in learning lists of nonsense syllables, regardless of the subject's previous preference and experience.

It is evident that no universal statement can be made regarding the comparative merits of the whole and part techniques. The answer is complicated by considerations of the kind and amount of material learned, the age and intelligence of the subject, his training, and any number of other factors.

The usual theoretical arguments against part learning have been disproved in one way or another. The argument that negative transfer occurs between units is refuted by the fact that successive units are learned more easily. The theory of retroactive inhibition of later on earlier parts is invalid since it can be used in refuting either method. In fact, Kline used it to explain the superiority of the part method in learning to solve cardboard puzzles. The argument that lapse of time between the learning of the earlier and later parts allows for forgetting is offset by the fact that each part receives more frequent repetition while it is being learned.

Two theories are apparently valid. One favors the whole method, the other the part. (1) Whole learning achieves an integration, which part learning can only achieve by extra effort in connecting the parts together. (2) Part learning offers easier units which can be adjusted to the capacity of the learner. Now the answer as to whether one or other of these two points is more important depends on the individual situation.

KIND AND AMOUNT OF MATERIAL

Amount of Material

Closely related to the problem of temporal distribution of practice effort is that of the most economical division of material to be learned. For example, if a list of ten items requires five repetitions, will a list of 20 items require just twice as many, or will it require less or more than this?

The first study, that of Ebbinghaus on nonsense syllable lists, showed that, as far as *total trials* to learn are concerned, there is economy in longer lists. The following table brings out this fact:

LENGTH OF LIST *No. of Syllables*	TOTAL TRIALS TO LEARN *No. of Trials*
7	1
12	16.6
16	30.0
24	44.0
36	55.0

Seven syllables fall within the memory span, and hence all lengths below it do also. Increasing lengths take proportionally longer, up to 16 syllables. Thereafter, the longer the list, the greater proportional economy in trials. During the initial rise there is an increase not only in repetitions, but also in repetitions per syllable; later repetitions per syllable need not increase. Data of Meumann and of Lyon confirm this finding. Henmon and Kjerstadt differ only in not finding the positive acceleration in trials required during the early stages. But their shortest lists were 10 syllables.

However, *total trials* does not give a constant criterion of learning effort when lists of different length are used. Thus, one trial for a list of ten syllables, provided each syllable is exposed 2 seconds, takes 20 seconds; whereas one trial for a 20-syllable list takes 40 seconds. This fact was not considered in the earlier studies. But Lyon and Kjerstadt reported data on the relation between length of list and *learning time.* And Robinson and Heron replotted the earlier data on a time basis as well as giving their own results on nonsense syllables in this form. The result is just the reverse of that for trials. *Learning time* increases at a faster rate than the length of list, giving a positively accelerated curve instead of the negatively accelerated curve obtained for *trials.* Some exceptions appear in the Meumann and Henmon curves but the general trend is the same. Robinson and Darrow duplicated the finding later on number material.

Recently Thurstone, in connection with the formulation of a rational equation for the learning curve, advanced the hypothesis that (a) the relationship between length of list and learning time should follow the law $T = \frac{c}{k} n\sqrt{n - a}$, in which T is the total learning time; k the subject's learning constant; n is the number of items in the list; and c expresses the degree of perfection required for complete learning. The a expresses the subject's memory span (i.e., the amount he can remember at a single trial) and hence becomes insignificant for longer lists. Therefore the law states that learning time varies approximately as the 3/2 power of the length of the list, expressed briefly as $T = \frac{c}{k} n^{\frac{3}{2}}$. (b) The relationship between length of list and number of trials or *repetitions to learn*, on the other hand, is $R = \frac{c}{k} \cdot \sqrt{n - a}$. This means that number of trials increases as the square root of the number of items in the list (corrected for the subject's attention span). Obviously the first law gives a positively accelerated curve and the second law a negatively accelerated one. When these theoretical curves are applied to the data of Lyon, Ebbinghaus, and others, they fit fairly well in the majority of cases.

Kind of Material

There are various ways in which learning material may differ in kind. Among the more important are differences in intrinsic meaningfulness, differences in complexity, differences in attentive value, and differences in affective and emotional tone or value. These overlap to a large degree, and the category of meaningfulness might be stretched to cover them all, but no advantage would be gained thereby.

Meaningfulness.—The discovery of a great difference between the facility and method of learning meaningful and non-meaningful material has led to the concept of two distinct kinds of memory, the so-called rote memory and logical memory. It is assumed that the two processes involved are distinct. The memorization of material which is devoid of meaningful associations is supposed to test the sheer retentivity of the nervous tissue for impressions. Ebbinghaus selected meaningless material for his classic quantitative experiments—the nonsense syllable. McDougall quotes Bergson's distinction between mechanical or repetitive memorizing, which he considers equivalent to motor habit formation, and recollection, which he considers true memory. If these are distinct processes, then efficiency in the one should not correlate as highly with efficiency in the other as though the two processes were identical. McDougall and Smith correlated the performance of 41 women students in learning nonsense syllables and learning a typewriter habit with their performance in recognizing ink blots and recalling the content of pictures and prose passages. They found that the nonsense syllable learning correlated highly with the typewriter habit, giving .61, while the ink blot and picture tests correlated highly with one another, .53. Yet these two groups gave practically zero correlations with each other. This is taken to mean that nonsense syllable learning, or any rote learning of meaningless material, is more nearly habit formation than it is memory. Jones and English obtained a correlation of .328 ± .08 between the scores of 56 college students on verbatim memorizing of prose passages and on recall of the ideas contained in prose passages. The results seem to favor a differentiation of ideational from rote memory.

As to the relative effort required in memorizing materials of different degrees of meaningfulness, the following chart from Reed's analysis of Lyon's data is significant:

Lyon learned	200	nonsense syllables	in 93 minutes
	200	Digits	in 85 minutes
	200	words of poetry	in 10 minutes
	200	words of prose	in 24 minutes
	700	words of poetry	in 91 minutes

An interesting study of McGeoch's brings out the relationship between the meaningfulness or associative value of nonsense syllables and the ease with which they are learned. He selected his lists from Glaze's chart of associative values of nonsense syllables, ranging from 0% to 100% associative value. McGeoch had 36 subjects learn lists of syllables having 0, 20, 46, 53, 73, and 100% associative values respectively. He found a definite tendency for number of syllables recalled to correlate with associative value.

Affective Tone.— The problem of the relation of *affect* or feeling tone to learning and memory is very complex because it is tied up with the *theoretical law* of *effect* (which is so often stated in affect terms) and because it is so closely related to the psychoanalytic theory of repression. The latter theory assumes that unpleasant material is automatically repressed, and hence forgotten. Experimenters have sometimes been at too great pains to defend or refute the theory. and the issues have been clouded thereby.

Nevertheless some development has taken place in the experimental procedure used. The earliest investigators contented themselves with questionnaires, asking their subjects what materials they recalled easiest, pleasant, unpleasant, or indifferent; or asking for a recounting of past events and then classifying them under the three feeling tones. The majority of studies relate to *retention* exclusively and will be discussed under that topic. Of those which bear on *learning,* the first was Kate Gordon's experiment in 1905 in which seven subjects, mostly Ph.D.'s, were asked to observe, and three weeks later to pass a recognition test on colored figures and protocols. The study gave negative results, as far as any effect of hedonic tone was concerned.

But Tait found that when lists of 20 pleasant, 20 unpleasant, and 20 indifferent words were passively observed by nine subjects, and were recalled later, the average number of pleasant words recalled was 10.5; of unpleasant, 8.2; and of neutral, 6.2. The pleasant words were recalled quickest. Note that unpleasant lists made a stronger impression than neutral lists.

Later, Tolman in a study of favorable conditions for memory compared the rate of learning of six subjects for lists of pleasant, indifferent, and unpleasant words. The affective tone of the words was previously judged upon independently. He found small differences, which however were corroborated in other ways. The pleasant lists required an average of 11.5 repetitions; the indifferent, 12.7; the unpleasant, 13.5. A defect is that he could not be *certain* that the words were pleasant or unpleasant to *all* the subjects alike. Griffits, in a similar experiment, corrected this loophole in the following way: He read through the list of 50 words to be learned three times, as though it were a list of free-association stimulus words, and the subjects' responses were classified for their affective tone. Then the subjects were asked to recall as many of the stimulus words as they could. He found that the words which caused pleasant associations had been learned best, the unpleasant ones next, and the indifferent ones least, thus corroborating Tait, rather than Tolman, as to the relative positions of unpleasant and indifferent words.

Fox found that 24 subjects learned most rapidly and recalled best the sonnets which were indicated as preferred by them. Anderson and Bolton presented their subjects ten unfamiliar odors each labelled with a nonsense syllable. Recall and recognition tests showed that the syllables presented with the pleasant or unpleasant odors were better fixated than the indifferent.

An interesting variation of technique is that of Whately Smith, who first obtained the subjects' galvanometric reaction to the words which were later thrown into lists to be learned. The words were then thoroughly learned. Recall tests showed that the words whose presentation elicited a decided galvanometric deflection were either learned with much greater or much less facility than words eliciting no deflection. Balken, in a recent study of a similar nature, failed to corroborate Smith. In summarizing the studies on affective value, it should be pointed out that, while considerable evidence points to the more efficient learning of affectively toned material as against neutral material, there is little to support the psychoanalytic theory of repression of the unpleasant. Undoubtedly the reason is because the kind of unpleasant material chosen did not arouse inhibitive attitudes. Bills, Flanagan, and Sharp, selecting sex and profane suggestion as probable sources of inhibitive reaction, gave subjects lists of nonsense-syllable paired associates in which such suggestions were hidden, and compared the rate of learning them with control lists in which entirely innocuous meanings were suggested. The former lists took, on the average, twice as long to learn, and the subjects' introspections showed that some sort of repressive process accounted for the difference.

MODE OF PRESENTING MATERIAL

AMONG the more important questions regarding method of presentation to which experimental answer has been given are: (a) Sense Avenue. (b) Order of Appearance. (c) Rate of Presentation. (d) Simultaneity or Successivity. (e) Organization, and (f) Environmental conditions.

Sense Avenue

Material may be presented visually, or auditorily, or in combination. During presentation, articulation may be suppressed, or oral recitation may be allowed. If recitation is used, then the method becomes either visual-articulatory, auditory-articulatory, or visual-auditory-articulatory. Recently the method of writing or tracing has been tried, in learning to read; i.e., the subject may read the word, hear it pronounced, pronounce it himself, and, in addition, trace or write it. This, then, would be a visual-auditory-articulatory-graphical method. The terms "kinaesthetic" or "motor" are sometimes used instead of graphical, but obviously all the methods involve kinaesthesis of one or another sort.

The discussion of these problems will be broken up into the following features: (1) the problem of the relative superiority of visual or auditory presentation; (2) the relation to these of a combined visual-auditory method; (3) the effect of adding a motor element, either articulation or writing; and finally (4) the special problem of reading and recitation in learning. It goes without saying that the results are in part a function of the learning method used, i.e., whether memory span or committing to heart, and in part dependent on the age of the subjects, the materials used and the way in which learning efficiency was measured.

Visual vs. auditory. — Henmon, in summarizing the results, emphasizes their lack of accord. The usual claim, partly substantiated by the careful study of Pohlmann on school children, is that children learn best all except nonsense material by the auditory method, whereas older children and adults find the visual method superior, due to their greater familiarity with written language, and their educational habits. But Henmon himself among others finds that the auditory method is better for adults too, regardless of the material, whether sense or nonsense, and irrespective of image type. Contradictory data of Münsterberg and Bigham and of Meumann favor visual presentation for all ages and materials, but Meumann recognizes that the person's imagery type determines his optimal method. Henmon considers it doubtful however whether the avenue of presentation determines the type of imagery which actually functions.

Auditory or visual alone vs. both combined. — Here again there is contradiction. Bigham and Smedley and Pohlmann found the combined method superior to either in isolation. Henmon corroborated this only for *visual,* not for auditory, while others report the single methods superior.

The effect of adding articulation or writing. — According to these motor methods, the subject pronounces the material in learning it or writes the material. In the preceding methods, articulation was prevented as far as possible. Most investigators agree that the suppression of articulation is detrimental to learning, but this is probably due to the distractive effect of suppressing it, rather than to the advantage of articulation. For example, Barlow had his subjects inhibit articulation by holding a pencil between the teeth. Considerable interference resulted.

But what is the effect of intentional articulation, as the oral pronunciation of the material to be learned, in rote memorizing? Does it have an advantage over silent learning? No satisfactory answer can be given. Articulation was found beneficial with children by Winch, and others, whereas Pohlmann found it detrimental. However this last experimenter had the oral learning done in unison, which almost certainly caused distraction.

With adults, it depends on the material. Henmon found it detrimental for words and nonsense syllables and Winch reports that adults learn to spell better silently, while, for poetry learning, Woody recently found oral learning superior for college students. However, if the problem is one of speed of grasping the meaning in reading a passage, then articulation is a drawback.

The other motor method is to have the subject write or trace the material to be learned. One of the chief investigators of this graphical method is Fernald who has found it beneficial in teaching retarded spellers. Kirk used the method with feeble-minded boys and found that, though the words were not learned more rapidly, they were better retained. Of course the theoretical significance for psychology of these experiments with motor methods of learning lies in their bearing on the question whether associations are formed on the efferent side of the neural arcs. This is the implication of the conditioned response theory, and of all theories which assume that it is acts which are associated rather than mere passive impressions. Obviously the results are too contradictory either to substantiate or refute the theory.

Recitation in memorizing. — The process of memorizing may or may not be accompanied by frequent recitation. In the case of the anticipatory method, each trial constitutes a recitation. With the paired associate technique, each presentation is alternated with a recitation. In the case of the complete exposure method, as many recitations may be called for as the experimenter chooses. The problem then becomes one of determining the optimal number of recitations in the process of learning. It has important implications for education.

Gates, using the complete exposure method with nonsense syllables and biographies, tried different percentages of the total time devoted to recitation. He used 4/5, 3/5, 2/5, 1/5 and zero time on recitation and found that learning efficiency varied directly with the percentage of the total time devoted to recitation. The effect is most pronounced in the case of the rote material.

Witasek tried distributing recitations according to a definite plan, in the learning of lists of 10 syllables, by university students. Four conditions were used, in which from 0 to 15 recitations were mixed with 6 to 16 readings. He concludes that recitations have a much greater learning value than reading; but the recitations are most effective when alternated with silent readings.

What is the optimum number of silent readings before a recitation? Skaggs and Grossman, using nonsense syllables and poetry, with ten trained subjects, found that it was best introduced after three readings, for both materials. William Krueger, using lists of paired monosyllabic nouns, with 108 college students as subjects, found that a recitation inserted during the latter half of the learning period was more beneficial than during the first half.

It should be pointed out that recitation is usually interpreted to mean recitation *with prompting,* or correction of errors.

Order of Appearance

To what extent is the rate of learning of items in a list affected by the temporal order of their presentation? Investigators are in almost universal agreement on this question. All sorts of material have been tried: nonsense syllables, colors, numbers, multiplication tables, photography, and stylus maze learning; and efficiency of learning has been tested in many ways. The universal finding is that the first and last terms in a series are learned quickest and best. This fact has led to the establishment of the laws of *primacy* and *finality.* Other things being equal, an item will be learned most effectively if it is presented first or last in a series. Usually the initial position is found to be slightly superior to the final position. Positions midway in a series are poorest of all. The advantage of the initial and final positions is shared by the immediately neighboring items, so that the second and third positions are superior to those midway in the series.

In a recent study, Robinson and Brown, using the anticipation method of learning nonsense syllables, obtained results on ten subjects for lists of 6, 9, 12, 15, and 18 syllables. They computed the percentage of correct anticipations for each item. The average results for the first repetition on twelve syllable lists are: —

PERCENTAGE OF CORRECT ANTICIPATIONS

Serial Order	1	2	3	4	5	6	7	8	9	10	11
Percentage	73.3	55.0	26.6	16.6	11.6	5.0	13.3	20.0	11.6	10.0	31.6

Comparable results on percentage of error at each position in a ten-digit memory span list are furnished by a study of Woodworth and Poffenberger: —

Position in Series	1	2	3	4	5	6	7	8	9	10
Percentage error	1	10	17	23	27	24	24	19	13	2

The first position is best; either the last or second positions are next, and the middle positions are poorest.

Warden studied the order of elimination of culs-de-sac in the learning of certain types of stylus maze and found that a primacy-recency order obtained, those near the entrance being eliminated first, those near the goal next and the intermediate group last, although the maze patterns used were especially adapted to a regressive order of elimination. The laws of primacy and recency are thus shown to apply to some trial and error motor learning as well as to memorizing. Warden's results are not universal, however, and many other factors apparently influence the order of cul-de-sac elimination.

As to the theoretical explanation of the primacy finality law, psychologists offer several hypotheses. Freedom from proactive interference favors the first item, and the last item is probably less subject to retroactive interference. It is also pointed out that the learner has longer to rehearse the first item before it reappears, but this could not explain the advantage of finality, nor the fact that the middle is the worst position. It is also probable that the advantage of association by place favors the first and last items, because of the prominence of their position.

Rate of Presentation, or Temporal Separation of Items

This topic is an important one because of the theoretical implications involved. Three distinct problems have been raised. First is the question whether association takes place simultaneously or successively and hence whether terms to be associated are best presented at the same instant or separated by an interval. Second is the question of the quantitative relation between the length of interval between terms and the rate of formation of associations. Third is the question whether association ever takes place in a reverse direction — i.e., backward association.

Although these problems were studied long before Pavlov's conditioned reflex technique was introduced into psychology, nevertheless some of the conditioned reflex experiments have interesting bearings on the problem. In Pavlov's original set up, the unconditioned response of a dog to the presentation of food — i.e., salivation — was conditioned to the sound of an auditory stimulus by presenting the two stimuli contiguously in time and repeating it often enough so that eventually the auditory stimulus would call out the response of salivation when given alone. In his and subsequent studies of conditioning, certain facts were brought out. First, the difficulty of establishing the conditioned reflex depended on the time interval between the two stimuli. Second, if the unconditioned stimulus preceded the conditioned stimulus, the association was difficult to establish. Cason attempted to condition the eyelid reflex to sound stimuli in humans. The procedure was to evoke the natural wink reflex by electrical stimulation and then simultaneously to give a sound stimulus of low intensity. He found that the conditioned reflex could not be established if the unconditioned stimulus — electrical shock— preceded the conditioned stimulus — sound. A third factor was the difficulty found by some experimenters in establishing the conditioned response, when the two stimuli occurred *simultaneously* instead of *successively*. Wolfle investigated these time relations quantitatively in the following way: she used the reflex jerk of the finger to an electric shock as her unconditioned reflex, and a sound as the conditioned stimulus. By varying the time of introducing the sound so that it preceded, came simultaneously with, and followed the shock, she was able to determine the effect of time on the percentage of successful conditioned reflexes established. Backward conditioning was rare, occurring in only 6 to 12% of the cases, and was very unstable. Simultaneity was also poor, giving only 10% success. The optimal intervals ranged between 0.2 and 0.6 seconds, with the conditioned stimulus preceding. The best interval was 0.3 seconds giving 58% successful conditionings, and with intervals of over 1 second no conditionings could be established. A good review of recent studies of the conditioned reflex is given by C. L. Hull in Chapter 9 of the Handbook of General Experimental Psychology.

first

late

The problem of the maximum time interval over which an association can be formed between two terms has been attacked in certain studies on animals. The animal situation is not exactly comparable to that of humans, because, as Hunter demonstrated in his delayed reaction experiment, the human can utilize the memory image in bridging a temporal gap, whereas the animal is less well equipped with symbolic representative processes to bridge such a gap. Thorndike assumed, on the basis of his experiment with cats, in which they learned to associate the act of handclapping with the presentation of food two seconds later, that the gap was bridged by an image. He could have assumed, however, that the connecting element was a third factor, namely his own presence, with which both terms were associated. This latter explanation is on the basis of the principle of 'mediate association' which assumes that two terms which are each associated with a common third term will be associated with each other, by indirect association.

Carr found, in an alternation problem with rats, in which he employed an interval of 16.5 seconds, that the animals were capable of mastering the problem with a high degree of proficiency. In a later series of studies in which intervals of 5, 10, 15, 25, and 35 seconds were used, he concludes that speed of forming the association is not a function of the size of the time interval between terms, within these limits.

Yarbrough tested the ability of rats to form an association between an electric shock stimulus and an auditory buzzer stimulus given at varying intervals preceding the electric shock. The first problem for the rats to learn was that when they received an electric shock, they would find the food box closed when they reached it, and hence must retrace their steps and go down the other alley to get food. When this had been learned, the auditory stimulus was then introduced at varying time intervals before the shock. Yarbrough found that there was an increasing difficulty of association with increase in the time interval between auditory stimulus and electric shock, but not at all proportionately. Between one and two seconds the greatest difference in difficulty occurred.

Let us turn now to the association studies with human subjects. Froeberg, using nonsense syllable pairs, presented visually, with immediate reproduction, tested seven subjects for efficiency of learning when the terms were presented at intervals of 0–5 seconds apart. The results are given below: —

Time interval	S	0	1	2	3	4	5 seconds
Average % reproduced	61	49	45	48	51	49	49

He attributes the failure to get reduction of learning efficiency with the longer time intervals to the persistence of the memory image of the preceding terms. He therefore performed a second experiment, to eliminate this factor. He compelled the subjects to fill the time between the presentation of the separate items by reading numbers to themselves to keep their minds off the syllables. He found that under these conditions the average percentages of right response were as follows: —

Time interval	0	1	2	3	4	5 seconds
Average % correct	54	45	34	36	24	22

Bergström found that the optimal interval depended on the material used. When nonsense syllables were used, and intervals of .302, .686 and 1.454 seconds occurred between items, the recall scores showed the least error for the longest interval; but when the material was lists of words, and when intervals of .5, 1.0 and 2.0 seconds were used, the best results were obtained for the shortest interval.

Investigations of remote association show that, for example, in learning a list of nonsense syllables, not only are associations formed between immediately succeeding syllables but also between remote syllables in the list. These associations however are weak. Whether this is due to the temporal interval between, or to the subject's set to associate only neighboring terms, is not known. But there is apparently a direct relation between temporal separation and weakness of bond.

Backward associations do occur but are far less efficient than forward associations. They have been reported by

Ebbinghaus, Cason, and others, for nonsense material; but Cason failed to obtain them with logical material.

Simultaneous vs. Successive Presentation

This problem is very closely related to the preceding one. If two terms are to be associated, will they be more easily connected if they are presented simultaneously (as in the case of paired associates) or successively (as with the serial method)? The theoretical significance of the problem rests on the dispute as to whether association ever takes place between terms unless they are experienced simultaneously. Those who hold this theory claim that where association does take place between *successive* terms, it is because the mental excitation of the first experience has not died away when the second is presented, and hence it reduces to simultaneity of presentation. Hence it becomes important to know whether simultaneity gives any more efficient condition for learning than successiveness of presentation.

Experimental tests of the theory have been made by several persons, including Bigham, Wohlgemuth, and Froeberg. With slight exception, all agree that the simultaneous method of presentation gives better results. For example, Bigham found that the simultaneous presentation of 20 colors, or numbers, for 40 seconds, gave an average error of 14.3%; whereas a successive presentation of the same items, allowing 2 seconds for a term, or 40 seconds in all, gave 20.8% error. However, there is a loophole in the method, since each term of a pair of series gets a considerably longer exposure under the simultaneous method. For example, Wohlgemuth found successive presentation much more effective in one test, in which each item or term of a pair was given the same duration of exposure under both simultaneous and successive conditions. We may conclude that the difference in duration of exposure rather than the simultaneity or successiveness of presentation was the important factor.

In comparing the studies of association with those of conditioning, we find that they agree in showing backward connections to be difficult. But they fail to agree in other respects. Simultaneous conditioning is difficult, while for association simultaneity is an extremely favorable condition. And whereas conditioning rarely occurs with longer temporal intervals than 1 second, apparently associations are formed over intervals of almost any length. There may be a progressive weakening of the association with the longer intervals but this has not been reliably demonstrated.

Organization — Rhythm

Material may be organized in various meaningful ways which add to the ease with which it can be learned and retained. One of these forms of organization is rhythm. There are two ways in which rhythm may enter into learning. On the one hand, the material itself may be intrinsically rhythmic, as poetry. Numerous studies demonstrate that such material is learned in shorter time and with less effort than prose passages of equal amount and difficulty. On the other hand, the rhythm may be imposed upon the material artificially. The question is, is learning facilitated by such externally imposed rhythms? Müller and Schumann had early reported a benefit from the presentation of nonsense syllables in iambic and trochaic rhythms with an advantage for the latter. Adams presented, to 160 subjects, several series of 9 or 10 random digits at a rate of 90–100 per minute. Recall was immediate and written. He used non-rhythmic and rhythmic presentation, with either two- or three-part rhythm. A clear superiority was demonstrated for the rhythmic method, but the relative effectiveness of two- and three-part rhythms depended on the total number in the list.

Environmental Factors

The learning process is influenced by the general conditions under which the learning takes place, and by the conditions of activity which immediately preceded the learning. The effect of different sorts of environmental context was investigated by Pan. Fifty-six subjects were required to learn paired associate lists of words with and without context and with variable context. The context consisted of words or numbers, typed above or below the paired word to be learned. Four presentations were given and amount learned was then tested. The contextual word was either (1) logically related to the second of the pair, or (2) to the first of the pair, or (3) to both, or (4) to neither. Only the first and third arrangements exerted a beneficial effect on learning. It is also important that the environmental conditions be constant. Any shift in the general pattern will not only inhibit recall, but will interfere with the learning process as well. Pan's study brought out the fact that any variation in the context words used during learning was detrimental. An unrelated context exerted a detrimental influence also, as did a contextual word which was related to the stimulus but not to the response.

The influence of prior activities, mental and physical, engaged in by the subjects, on the efficiency of a subsequent learning period, was investigated by Whiteley. The prior physical activity consisted of vigorous calisthenics for five minutes, while the prior mental activity consisted of performing thirty problems in multiplication of two-place numbers. The learning material was lists of three- and four-letter monosyllabic words, serially exposed. Whiteley found no effect of the prior activities on the rate or quality of the learning. A later study in which the prior activity consisted in the arousal of a general ideational context related to the material to be learned, i.e., an apperceptive mass, also gave negative results. The method of arousing the related context was (1) to require the subject to read and study a brief résumé of the given field of knowledge, or (2) to answer a series of specific questions covering the field of knowledge from which the words to be learned later were chosen. These negative results are hardly conclusive. A list of isolated words is, like a list of nonsense syllables, learned largely by the rote method with the help of more or less chance associations. The experiment ought to be repeated with the learning of connected material, and material which is tinged with a common emotional attitude or mood. Both congruous and incongruous materials should be used and compared. The fact that Whiteley obtained a slightly detrimental effect from related context suggests that some negative transfer obtained.

REFERENCES

Adams, H. F. A note on the effect of rhythm on memory. *Psychol. Rev.*, 1915, 22, 289–298.

Anderson, A. C., & Bolton, F. J. The inhibition of the unpleasant. *J. Abn. & Soc. Psychol.*, 1925, 20, 300–302.

Austin, S. M. A study in logical memory. *Amer. J. Psychol.*, 1921, 32, 370–403.

Barlow, M. C. The role of articulation in memorizing. *J. Exper. Psychol.*, 1928, 11, 306–312.

Barton, J. W. Smaller vs. larger units in learning the maze. *J. Exper. Psychol.*, 1921, 4, 418–429.

Bergström, J. A. Effect of changes in the time variables in memorizing. *Amer. J. Psychol.*, 1907, 18, 206–238.

Book, W. F. The psychology of skill. New York: Gregg, 1925.

Brown, R. W. A comparison of the 'whole', 'part', and 'combination' methods of learning piano music. *J. Exper. Psychol.*, 1928, 11, 235–247.

Brown, W. Whole and part methods of learning. *J. Educ. Psychol.*, 1924, 15, 229–233.

Carr, H. A. The alternation problem. *J. Animal Behav.*, 1917, 7, 365–384.

Carr, H. A. Length of time interval in successive association. *Psychol. Rev.*, 1919, 26, 335–353.

Carr, H. A. Distribution of effort. *Psychol. Bull.*, 1919, 16, 26–28.

Crafts, L. W. Whole and part methods with non-serial reactions. *Amer. J. Psychol.*, 1929, 41, 543–563.

Culler, A. J. The effect of distribution of practice upon learning. *J. Phil.*, 1912, 9, 381–383.

Cummins, R. A. Improvement and the distribution of practice. *Teach. Coll. Contrib. Educ.*, 1919, No. 17.

Ebbinghaus, H. Memory. (Trans. by Ruger and Bussenius.) New York: Teach. Coll., Columbia Univ., 1913.

Ebert, E., & Meumann, E. Ueber einige Grundfragen der Psychologie der Uebungsphänomene in Bereiche des Gedächtnisses. *Arch. f. d. ges. Psychol.*, 1905, 4, 1–232.

Fernald, G. M., & Keller, H. B. The effect of kinaesthetic factors in the development of word recognition in the case of non-readers. *J. Educ. Res.*, 1921, 4, 355–377.

Fox, C. The influence of subjective preference on memory. *Brit. J. Psychol.*, 1922–23, 13, 398–405.

Froeberg, S. Simultaneous versus successive association. *Psychol. Rev.*, 1918, 25, 156–163.

Gates, A. I. Recitation as a factor in memorizing. *Arch. Psychol.*, 1917, No. 40.

Gopalaswami, M. Economy in motor learning. *Brit. J. Psychol.*, 1925, 15, 226–236.

Gordon, K. Ueber das Gedächtnis für Affektiv bestimmte Eindrücke. *Arch. f. d. ges. Psychol.*, 1905, 4, 437–458; 459–464.

Gordon, K. Class results with spaced and unspaced memorizing. *J. Exper. Psychol.*, 1925, 8, 337–343.

Griffits, C. H. Results of some experiments on affection, distribution of associations, and recall. *J. Exper. Psychol.*, 1920, 3, 447–464.

Hardy, M. C. The effect of distribution of practice in learning a stylus maze. *J. Comp. Psychol.*, 1930, 10, 85–96.

Henmon, V. A. C. The relation between learning and retention and amount to be learned. *J. Exper. Psychol.*, 1917, 2, 476–484.

Henmon, V. A. C. The relation between mode of presentation and retention. *Psychol. Rev.*, 1912, 19, 79–96.

Hull, C. L. Learning II, Chapter 6, in Murchison's Handbook of General Experimental Psychology, Clark Univ. Press, 1934.

Jones, M. G., & English, H. B. Notional vs. rote memory. *Amer. J. Psychol.,* 1926, 37, 602–603.

Jost, A. Die Assoziationsfestigkeit in ihre Abhängigkeit von der Verteilung der Wiederholungen. *Zsch. f. Psychol.,* 1897, 14, 436–472.

Kjerstad, C. L. The form of the learning curve for memory. *Psychol. Monog.,* 1919, 26, No. 5.

Koch, H. L. A neglected phase of the part-whole problem. *J. Exper. Psychol.,* 1923, 6, 366–377.

Lakenan, M. E. The whole and part methods of memorizing poetry and prose. *J. Educ. Psychol.,* 1913, 4, 189–198.

Lashley, K. S. A simple maze: with data on the relation of the distribution of practice to the rate of learning. *Psychobiol.,* 1918, 1, 353–357.

Lashley, K. S. The acquisition of skill in archery. *Carnegie Publ.,* 1915. No. 211, 61–83.

Lyon, D. O. Memory and the learning process. Baltimore: Warwick and York, 1917.

Lyon, D. O. The relation of length of material to time taken for learning, and the optimum distribution of time. *J. Educ. Psychol.,* 1914, 5, 1–9, 85–91, 155–163.

McClatchy, V. R. The optimal position of a rest period in learning. *J. Exper. Psychol.,* 1925, 8, 251–277.

McGeoch, J. A. The influence of associative value upon the difficulty of nonsense-syllable lists. *J. Genet. Psychol.,* 1930, 37, 421–426.

McGeoch, G. O. The intelligenec quotient as a factor in the whole-part problem. *J. Exper. Psychol.,* 1931, 14, 333–358.

Meumann, E. Vorlesungen zur Einführung in die *Experimentelle Pädagogik,* 1907, p. 121.

Meumann, E. The psychology of learning. (Trans. by J. W. Baird.) New York: Appleton, 1913.

Müller, G. E., & Schumann, F. Experimentelle Beiträge zur Untersuchung des Gedächtnisses. *Zsch. f. Psychol.,* 1894, 6, 81–190, 257–339.

Münsterberg, H., & Bigham, J. Memory. *Psychol. Rev.,* 1894, 1, 34–38.

Pan, S. The influenec of context upon learning and recall. *J. Exper. Psychol.,* 1926, 9, 468–491.

Pechstein, L. A. Whole vs. part methods in motor learning. *Psychol. Monog.,* 1917, 23, No. 2.

Pechstein, L. A. Massed vs. distributed effort in learning. *J. Educ. Psychol.,* 1921, 12, 92–97.

Perkins, N. L. Value of distributed repetitions in rote learning. *Brit. J. Psychol.,* 1914, 7, 253–261.

Pohlmann, A. Experimentelle Beiträge zur Lehre vom Gedächtnis, Berlin, 1905.

Pyle, W. H., & Snyder, J. C. The most economical unit for committing to memory. *J. Educ. Psychol.,* 1911, 2, 133–142.

Pyle, W. H. Concentrated vs. distributed practice. *J. Educ. Psychol.,* 1914, 5, 247–258.

Reed, H. B. The part and whole methods of learning in prose and poetry. *J. Educ. Psychol.,* 1924, 15, 107–115.

Reed, H. B. Repetition and association in learning. *Ped. Sem.,* 1924, 31, 147–155.

Robinson, E. S. The relative efficiencies of distributed and concentrated study in memorizing. *J. Exper. Psychol.,* 1921, 4, 327–343.

Robinson, E. S., & Brown, M. A. Effect of serial position upon memorization. *Amer. J. Psychol.,* 1926, 37, 538–552.

Robinson, E. S., & Darrow, C. W. Effect of length of list upon memory for numbers. *Amer. J. Psychol.*, 1924, 35, 235–243.

Robinson. E. S., & Heron, W. T. Results of variations in length of memorized material. *J. Exper. Psychol.*, 1922, 5, 428–448.

Ruch, T. C. Factors influencing the relative economy of massed and distributed practice in learning. *Psychol. Rev.*, 1929, 35, 19–45.

Skaggs, E. B., Grossman, S., Kreuger, L., & Kreuger, W. C. F. Further studies of the reading-recitation process in learning. *Arch. Psychol.*, 1930, 18, No. 114.

Smith, M., & McDougall, W. Some experiments in learning and retention. *Brit. J. Psychol.*, 1919–20, 10, 199–209.

Smith, W. W. The measurement of emotion. New York: Harcourt Brace, 1922.

Steffens, L. Experimentell Beiträge zur Lehre vom ökonomischen Lernen. *Zsch. f. Psychol.*, 1900, 22, 321–382.

Swift, E. J. The acquisition of skill in typewriting. *Psychol. Bull.*, 1904, 1, 295–305.

Tait, W. D. Effect of psychophysical attitudes on memory. *J. Abn. & Soc. Psychol.*, 1913–14, 8, 10–38.

Thurstone, L. L. The relation between learning time and length of task. *Psychol. Rev.*, 1930, 37, 44–53.

Warden, C. J. The distribution of practice in animal learning. *Comp. Psychol. Monog.*, 1923, 1, No. 3.

Warden, C. J. Primacy and recency as factors in cul-de-sac elimination in a stylus maze. *J. Exper. Psychol.*, 1924, 7, 98–116.

Whiteley, P. L. The dependence of learning and recall upon prior mental and physical conditions. *J. Exper. Psychol.*, 1924, 7, 420–428.

Whiteley, P. L. The dependence of learning and recall upon prior intellectual activities. *J. Exper. Psychol.*, 1927, 10, 489–508.

Winch, W. H. Experimental researches on learning to spell. *J. Educ. Psychol.*, 1913, 4, 525–537, 579–592; 1914, 5, 449–460.

Winch, W. H. Should poems be learned by school-children as 'wholes' or in 'parts'? *Brit. J. Psychol.*, 1924, 15, 64–79.

Witasek, S. Ueber Lesen und Rezitieren in ihrer Beziehungen zum Gedächtnis. *Zsch. f. Psychol.*, 1907, 44, 246–278.

Wohlgemuth, A. Simultaneous and successive association. *Brit. J. Psychol.*, 1914–15, 7, 434–452.

Wolfle, H. M. Conditioning as a funtcion of the interval between the conditioned and the original stimulus. *J. Gen. Psychol.*, 1932, 7, 80–103.

Woody, C. The effectiveness of oral versus silent reading in the initial memorization of poems. *J. Educ. Psychol.*, 1922, 13, 477–483.

Wylie. G. E. Whole vs. part methods of learning as dependent upon practice. Ph.D. thesis: University of Chicago, 1928.

Yarbrough, J. U. The influence of the time interval upon the rate of learning in the white rat. *Psychol. Monog.*, 1922, 30, No. 135.

CHAPTER XII

FACTORS INFLUENCING THE EFFICIENCY OF LEARNING [*continued*]

TUITION

CLOSELY related to the problem of method of presentation is that of the amount and form of artificial aid or tuition that should be imparted to the subject in learning. Tuition may take several forms. It may involve (1) the artificial prevention of errors, or (2) putting the subject through the correct act, or (3) demonstrating the correct act in one of several ways, or (4) calling attention to the salient features of the problem situation and its solution, through verbal directions or other means.

While the most obvious application of such studies is to educational method, certain theoretical questions are incidentally subjected to experimental test thereby. One is the all-important question of the value of frequency or sheer repetition of an act in its fixation. Another is the question of the relative importance of elimination of incorrect responses versus fixation of correct responses, in learning a new habit. A third is the problem of the legitimacy of the concept of imitation. And a final question is that of the relative effectiveness of verbal explanation versus actual performance as a pedagogical device, both in the learning of particular things, and in the building up of generalizations which will transfer to other related situations.

Mechanical Guidance. — This method has been used in maze situations, animal and human. It consists in blocking the culs-de-sac so that the subject is prevented from making errors. Practice is thus limited to the correct path during a given number of trials. Thereafter guidance is removed. The ultimate performance of such a group is compared with that of a control group to whom no guidance is given from the start. Carr and Koch, using an alternation problem with rats, in which one group were given 640 guided, followed by 160 unguided trials, and the other group 800 trials without guidance, found that the unguided group of rats consistently made the better records. When guided runs were inserted at the end instead of at the beginning, no difference could be observed. Koch repeated the experiment on a standard maze, and systematically varied the number of guided trials and the stage in the learning process at which they were inserted, with different groups. Both an animal and a human experiment were run. The results with human subjects are shown in the table. The figures in brackets indicate at what stage in the practice the guided trials were introduced.

✓THE INFLUENCE OF MECHANICAL GUIDANCE WITH HUMAN SUBJECTS

Number of guided trials	Number of Undirected Runs that are Equivalent to one Guided Run					
2	3.7 (1–2)	−3.0 (3–4)	.6 (5–6)	1.6 (7–8)	4.3 (9–10)	3.0 (11–12)
4	1.8 (1–4)		.15 (5–8)		1.7 (9–12)	
6	.1 (1–6)			1.2 (7–12)		
8	−1.6 (1–8)				.9 (9–16)	
12	−.12 (1–12)					

In general, the guided runs were superior to an equivalent number of unguided runs, but the effectiveness of the guidance tends to decrease with the amount given. More than four guided trials are less beneficial than an equal number of unguided, and more than six are actually detrimental to learning. A small number of guided trials is most effective when placed either at the beginning or end of learning.

Guidance may be withdrawn abruptly or gradually. Tsai demonstrated with animals and Lowes with humans that gradual withdrawal is no more efficacious than abrupt, and under certain circumstances is less so.

These experiments offer a direct answer to the question of the importance of trial and error, with emphasis on error, in learning. A maze cannot be learned unless the subject has some experience with the incorrect movements.

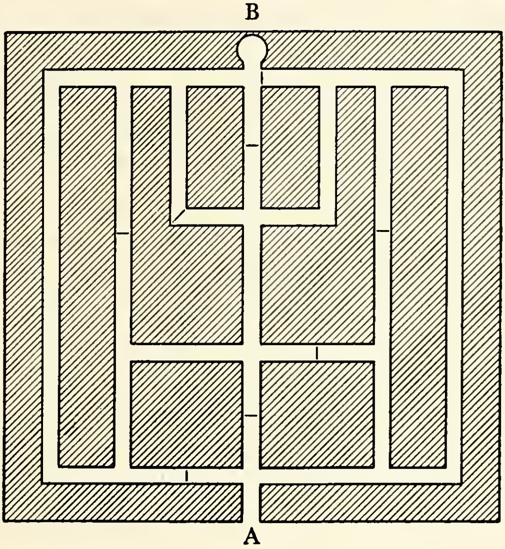


FIG. 64. Visual maze. Carr

From J. Exper. Psychol., 1921, 4, p. 400, Fig. 2.

Putting Through. — If the subject's hand is guided a number of times over the correct path in a maze, will such repetitions fixate the act? Or must the subject be allowed to do his own active exploring? Ludgate answered this question in a human maze experiment in which she grasped the hand of the subject and guided it over the true pathway. Different amounts of such guidance were given, either at the start, or after the subject had had some opportunity to explore the maze pattern on his own initiative, and the subject was then asked to run the maze alone. She found guidance effective if given in small amounts, and after some preliminary exploration; otherwise it might prove detrimental.

Waters recently found that large amounts of manual guidance, 20, 40, and 80 guided trials, were increasingly beneficial when the subject assumed an active attitude during guidance, but the proportionate increase was not maintained.

This and the preceding studies demonstrate that mere *frequency,* or repetition, is not, in itself, effective in learning a habit. The repetition must be accompanied by success or failure, and must involve an active, exploratory process.

Other Forms of Guidance. — In addition to the previous forms of guidance, two other kinds have been used — visual and verbal. Ordinarily the subject is blindfolded in stylus maze learning. But various forms and amounts of visual control can be allowed. The Carr visual maze permits full vision of the head and stylus, and main runway, but the true path cannot be distinguished from a cul-de-sac. The advantage of such guidance is equivocal. Another method is to show the subject a diagram of part or all of the maze before he runs it. This sort of guidance is beneficial in proportion to its amount.

By the verbal method, the subject is given directions as to the true path, while traversing the maze, or is informed of his errors. The results of such a method are shown below. Obviously, a small amount given early is beneficial, but its effectiveness rapidly decreases with the amount given.

NUMBER OF UNGUIDED TRIALS EQUIVALENT TO EACH GUIDED RUN

			Verbal Directions	
10.7	7.3	4.8	1.4	.9
(1)	(1–2)	(1–4)	(1–8)	(1–16)
			Error Information	
11.7	6.6	5.4	1.9	.18
(1)	(1–2)	(3–4)	(7–8)	(11–12)

The verbal methods prove most effective. In the main, the value of guidance decreases as the amount increases, and the later it is introduced in the learning process.

Tuition in Rational Learning. — Is tuition more effective in the solving of more abstract problems? Waters answered this question by devising the following experimental problem which is an adaptation of J. C. Peterson's "rational learning" problem.

The subject is presented with a row of beads — say, seven, strung on a wire. He is told that he and the experimenter will be allowed to draw alternately, taking either one or two each time, until all are drawn. He is given the first draw. He is to draw in such a way that he gets the last draw. To solve this problem he must discover the method of always arranging his draws so that the remaining number is a multiple of the sum of the highest and lowest draws allowed, — in this case, three. Four types of tuition were tried: (1) Demonstration; (2) Direction of attention; (3) Error information; and (4) Instruction, concrete and abstract. The "direction of attention" method consisted in having the subject call out the number of beads remaining after each draw. The concrete instruction was the statement: "Always draw so as to leave a multiple of 3." The abstract instruction was, "Always draw so as to leave a multiple of the sum of the highest and lowest possible draws."

Of all these methods, the verbal instruction was best, and the concrete form was superior to the abstract, even though the concrete statement was only applicable to the first form of the problem, while the abstract fitted any form. Instruction can apparently be so general as to be impracticable. The demonstration method exerted a distinctly detrimental effect on the solution of the problem, merely confusing the subjects. Both the "attention" method and the "error information" method exerted a beneficial effect in learning the first form of the problem, but error information failed to transfer an advantage to the subsequent forms.

In so far as a generalization can be drawn from these results on tuition, in the aggregate, we can say that the concrete verbal instruction is superior to all other methods. If imitation is a factor in learning, the experiment of Waters certainly gives no evidence of it.

ATTITUDES: ATTENTIVE, VOLITIONAL, AND EMOTIONAL

THUS far our discussion has been confined to the mechanical factors which have to do with the external mode of stimulation in learning and lie outside the learner himself in the main. But learning is not mere passive reception of stimulations. It is an active coöperative performance on the part of the subject. There is reason to suppose that mere passive receptivity would never result in the acquisition of anything. Historically, the mechanical, passive, aspect of learning was chiefly emphasized by the English Associational School, while the other aspect, the active, coöperative feature, was emphasized in German Voluntarism and the "apperception" concept. It stresses the rôle of the individual in actively acquiring rather than passively receiving impressions. It is closely related to, though not necessarily identified with, the motor psychology which conceives of associations as formed on the efferent side of the sensori-motor arcs, in connection with active behavior. The question is raised, therefore, as to what dynamic attitudes of the learner are most conducive to effective learning. These attitudes are either attentive, or volitional, or emotional in nature.

Attentive Attitudes

The point has been made, in the discussion of Attention, that the attentive process is a complex affair consisting of an adjustment of the sense organ for the better reception of stimulation; a mobilization of the central nervous processes consisting of the facilitation of relevant and inhibition of irrelevant impulses; and an adjustment of the muscles for effective response, consisting in the main of increased tension. On the subjective side, attention is measured by the increase in the clearness of consciousness. Hence, experimental studies of attention in learning are concerned with either (1) the subject's degree of consciousness, or knowledge of results, or his degree of concentration of attention; or (2) the muscular attitude or set under which learning takes place.

Knowledge of Results.—To what extent, if at all, does learning take place when the subject has no knowledge of the correctness of his previous performance? The early functionalists, Angell for example, made consciousness and learning inseparable. Consciousness arises at the point where the organism is unable to adjust itself to its environment by the utilization of ready formed behavior patterns. However, all degrees of awareness accompany learning. In acquiring acts of skill, such as balancing on a wire, or swimming, consciousness is only with regard to the situation as a whole. We are not aware of the many fine and rapid adjustments of equilibrium and posture required to maintain balance. Perrin demonstrated, in an introspective study of the learning of balancing and coördination tests, that consciousness is at a minimum throughout. The question should, then, be restated. What amounts and what sorts of knowledge must accompany learning, and to what degree is the efficiency of the learning process influenced thereby?

It can be shown that, in experiments aimed to test this question, not all knowledge has been eliminated. For example, in Judd's early study of " Practice Without Knowledge of Results " the subject was seated before a table divided into two parts by a screen, so that he could see only one part. Sheets of paper were prepared with lines drawn from the center of the paper to the right hand edge at 9 different angles to the horizontal, namely +60°, +45°, +30°, +15°, 0°, —15°, —30°, —45°, and —60°. These were successfully set up before the screen, and the subject was required to place a dot at the point beyond the screen where he thought the extended line should fall. Each subject was given several trials with each angle. His results were checked against the actual extension of the line drawn beyond the screen. But he was not told either the amount or direction of his error. The subject went through the whole series of nine lines twenty times each day for ten days. Judd reports that practice, under these conditions, brought practically no improvement in accuracy. Spencer criticised this conclusion on the ground that Judd added his subject's plus and minus errors algebraically instead of disregarding sign and hence had no estimate of total size of error. When the latter method of computation is tried, an improvement of 11% is noted. Repeating the experiment on four subjects, Spencer found considerable improvement in the records of three of them. The results demonstrate, not that learning can occur with no knowledge of performance, but that very indirect kinaesthetic visual cues can be utilized. The significant fact is that improvement under these conditions is so slight as compared with that in situations in which the subject has direct visual-motor knowledge of his error.

Incidental Memory. — Memory for items to which attention has not been specifically directed by the task is known as incidental memory. It has been investigated by many methods. The Aussage, or testimony method, of Stern consisted of presenting the subject with an event or scene and later questioning him regarding particular items. The disadvantage is that there is no certainty that the subject has seen the items called for. Hence the test is one of span of attention or observation, rather than memory. Shellow has listed the requirements of a test of incidental memory, the most important of which are: (1) perception of the material later to be recalled must be assured, and (2) a diverting direction or aufgabe must be given to occupy the attention and insure that direct learning of the material used for incidental memory does not occur; (3) the question must require sheer memory rather than depend upon judgment or previous knowledge.

Myers tested incidental memory for words by telling his subjects that they were to be given a spelling test and then dictating a lot of words to them. Immediately after they were told to turn over the page and write down the words in order. The scores were far inferior to those of another group who were informed that recall would be expected. Myers also used the " letter square " test, in which a board with red letters on a yellow background outlined in black was presented to the subjects, and they were to correct the letter " o's." Later they were questioned as to the other letters, the color of the letters and background, etc. He found that the amount of incidental memory was very small. Shellow performed several tests on large numbers of subjects to determine individual differences, variability, and other factors in incidental memory. In one of her tests she presented twelve magazines to the subjects. They were told to look at each carefully and try to remember the name and order in which it came and that they would be asked to write down their names in order later. They were then asked a series of questions about the pictures on the covers. She found wider variations in incidental than in direct memory, but the two types of memory correlated rather well. She found that incidental memories could always be explained in terms of some interest or purpose of the subject and hence were never completely "incidental."

Distractions, in so far as they tend to reduce the attention given to the material being memorized, should interfere with learning efficiency. Foucault found that certain types of distraction interfered, but mechanical noise did not, and when the subject had previously worked with noise, its removal produced a disturbance in the subsequent learning process. Morgan, on the contrary, found distracting noises in the form of a phonograph, an electrical buzzer, and a fire gong detrimental to the learning and recall of paired associates. Apparently only attention-compelling stimuli or unusual ones interfere.

Muscular Attitude. — If attention involves muscular tension, then will the voluntary assumption of the bodily attitude of attention facilitate learning? Bills tested the influence of such voluntarily induced tension on the efficiency of memorizing of nonsense and sense material. Subjects were asked to squeeze stationary dynamometers, one with each hand, while learning serial lists of nonsense syllables and of sense words visually exposed

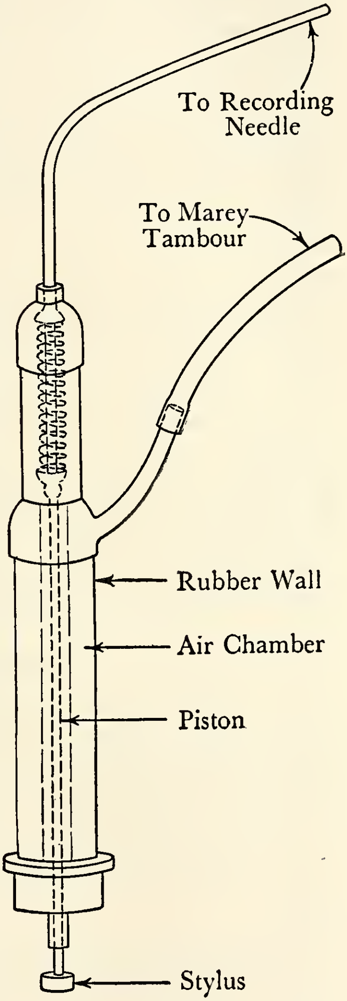


Fig. 65. Stroud's pressure pencil for studying tension in maze learning

A control group learned without tension. One list was learned each day for several days. At the start, the non-tension condition was slightly superior, but as the strangeness wore off, the tension condition rapidly assumed the superior position. A related experiment was performed by Stroud on voluntary tension in stylus maze learning. A specially devised pressure stylus shown in Figure 65 yielded kymographic record of the amount of tension exerted by the active hand. The subject maintained a tension of 14 pounds with the inactive hand, during learning. The results show that efficiency of learning, as measured by time, errors, and trials, was practically doubled by tension. On the other hand, Russell demonstrated that muscular tension, especially of the active member, is detrimental in the learning of acts of skill, such as ball tossing at a target.

The tension here interferes with the free play of the muscles. The benefit of tension in ideational learning is probably to be attributed in part to the attitude of effort or voluntary exertion which is thereby established and which is ideational as well as muscular. A general facilitation of the central process is achieved.

Volitional Attitudes

The distinction between attentional and volitional attitudes is not clearly drawn. Investigations of volition cover the following special topics: (1) Active vs. passive attitudes, or intention to learn; (2) Learning with definite or indefinite expectation of recall vs. no expectation; and (3) Backward and remote associations versus forward and direct ones.

Smith and McDougall compared "active" and "passive" attitudes in learning. They presented lists of twelve nonsense syllables to two subjects, working under two different attitudes. Under one, they were to make an effort to learn the list as soon as possible; under the other, to maintain a "passive" attitude, and to allow mechanical or rote learning to operate. Learning under the "active" attitude required on the average 9 repetitions for one, and 13 repetitions for the other subject. Under the passive attitude, an average of 89 and 100 repetitions were required. A relearning test showed no better retention for the passively learned lists, in spite of the tremendously greater learning time.

That this difference in attitude is objectively measurable was shown by Balken. She took psychogalvanic reflex measurements of subjects while they learned lists of words under the "active" and "passive" attitudes respectively. Not only did the subjects learn better under the active attitude, but larger and more frequent galvanic deflections accompanied it, probably showing a heightened muscular tonus under this attitude.

Book and Norvell investigated the factor of "will to learn." They studied the practice gain of 124 college students in simple tasks involving crossing out letters, two place multiplications, etc., over a long period of practice. The "will" group were told of their previous scores and urged to surpass them. The control group were told nothing. Not only did the stimulated group improve much faster, but the control group, when stimulation was later introduced, suddenly leaped ahead at a rapid rate.

Determination to remember was studied by Achilles. Two groups of 25 each arranged photos with names attached, according to attractiveness, and syllables according to ease of articulation. One group was given the determination to remember the items, the other not. Learning, as tested by recall, was much poorer for the group without determination; they recalled 81.3% as many syllables and 57.2% as many photos. The recognition scores were less affected.

An additional factor was brought out by Peterson. He found that determination to learn assists delayed recall more than it does immediate recall. The improvement in the former averaged 50%, while that in the latter was only from 15 to 30%.

When the individual is informed that recall will be required, his learning is more efficient than otherwise. Moreover, any shifts in the expected time or expected conditions of recall affect its efficiency, due to the fact that the learning is performed under a specific volitional set which is determined by the expectations of the learner.

Woodworth read a list of twenty pairs of unrelated words to 16 subjects instructing them to learn them so as to be able to give the second of each pair when the first was read. After three readings he informed them that they should also give the first of each following pair on getting the second of the preceding pair as stimulus. When he then tested their recall he found that the second members of the pairs were correctly recalled in 74% of the cases, but the first members in only 7% of the cases. Intention or volitional attitude accounted for the difference.

Boswell and Foster compared the learning of material for permanent retention with learning for immediate recall, to determine whether there is any difference in the learning process under these two sets. Four subjects learned lists of fifteen paired English-Chinese vocabulary words, for sixteen repetitions. One set of lists was learned with the instruction that recall would be in five minutes. The other was learned with the instruction that recall would be tested in five minutes, and again in two weeks. As measured by recall efficiency, the results are ambiguous. But there is a slight benefit from the permanent-retention set as regards recall after two weeks, which is borne out by the introspections of the subjects. They learned with a different degree of effortfulness for the longer retention. Geyer demonstrated the influence of changing the expected time of recall, in a more elaborate study, which will be described later, under the topic of Recall. Her results corroborate Foster's, that the learner's expectations determine the mode of learning.

Backward and remote associations are learned with far less facility than the direct and contiguous ones. Presumably associations in the backward direction are hindered by the fact that they run counter to the subject's volitional set, which is toward making forward associations. Ebbinghaus' early findings for nonsense material have been corroborated by Cason. Backward associations for paired nonsense syllables and words are formed in the ratio of two out of three. But with logical material, backward associations failed to appear, and instead, inhibiting associations were formed which interfered with learning in the reverse direction.

Cason also found that forward remote associations, in lists derived from passages of prose and poetry, were extremely rare.

Emotional Attitudes

Although the importance of emotional attitudes in learning has always been recognized, and though their influence has been pointed out by Book and others in studies of acquisition of skill, the degree of their influence has not been quantified. Excitement, pleasure, and feelings of well-being are facilitative, and ennui and depression are inhibitive.

To what extent do emotional attitudes toward specific stimulus materials function? When the nature of the material is such as to arouse emotional complexes, does the psychoanalytic principle of repression actually operate to inhibit association? Bills, Flanagan, and Sharp tested the hypothesis in the following way.

Lists of paired associate nonsense syllables were constructed, of two sorts. In Experiment I, one kind consisted of pairs which when pronounced together sounded like objects used in farming, as *har-nis,* etc. The other kind consisted of pairs which when pronounced together sounded like salacious words. In Experiment II, one kind contained pairs which sounded like sports, as *gol-luf,* and the other, pairs which suggested sacrilegious words, as *gad-dem.* Fifty-six students acted as subjects in Experiment I, half learning the non-salacious and half the salacious words. The results show a considerable increase in learning time for the salacious lists. Recall was also seriously inhibited by the emotional complex aroused by the salacious material. In Experiment II, 120 subjects, all Normal School girls, were divided into two groups, one group learning the profane sounding list and the other learning the innocuous one. Again, the emotional complex was effective in inhibiting the learning and recall of the profane list. Whereas the average number of repetitions for the innocuous list was 7.61; for the profane material it was 14.65; and, whereas the former group had an average recall of 12.80 syllables, after 24 hours, the latter recalled only 8.0.

Sullivan studied the effects on nonsense syllable learning of emotional attitudes of "failure" and "success" brought about by leading the subject to believe that he is better or poorer in his performance than the other members of his own group. Adult subjects of high intelligence and low intelligence were used, and also a group of children. "Failure" attitudes were produced by reporting to the subject fictitiously low scores made by himself as compared with the rest of the group; "success" attitudes were produced by reporting his scores as fictitiously high. In general, "failure" attitudes tended to lengthen subsequent learning times, while "success" attitudes tended to shorten them. "Success" attitudes had the greatest effect on the low intelligence group, and on the children, in shortening their learning time, while failure had the greatest effect on the high intelligence group.

McKinney produced similar emotional attitudes in subjects learning stylus mazes, by telling them that they ought to learn the maze in a fictitiously short time. The result was that the subject became tremendously upset, crying or swearing, and learning time was tremendously increased.

Several studies have brought out the effect of emotional attitudes aroused during retention or at the time of recall, which will be discussed later.

MOTIVES AND INCENTIVES

VERY closely related to the problem of "*effect*" in learning is that of the extra or artificial incentives introduced into the situation to motivate the learner.

It is necessary to distinguish between motive and incentive. Properly speaking, an incentive is some environmental object or condition, the attainment or avoidance of which motivates the individual in his behavior. The motive, on the other hand, is the condition or set of the organism directing and energizing it toward a specific line of conduct. Motives are complex, variable, and difficult to isolate. However, particular incentives may be systematically experimented with, and such studies have been directed to the following special factors: (1) Reward and punishment; (2) praise and blame, or encouragement and discouragement, or positive versus negative instructions; (3) knowledge of one's previous record; (4) attitudes of success and failure; (5) competition and rivalry; and (6) social facilitation where rivalry is not explicit.

Studies on animals have been concerned with learning with and without incentive, with various strengths of incentive, and with comparative efficiency of different incentives, chiefly hunger, sex, escape, and punishment. A consistent superiority has been demonstrated for the food incentive in these experiments. The question has been raised as to whether an animal would improve at all in a habit, provided the incentive were removed. Sharp tested the problem, by first giving his animals a food incentive, in preliminary practice on a maze, and then removing the incentive and continuing the runs. The speed and accuracy records of the rats suffered a sharp decrement at first, but improved slowly but steadily thereafter. It is probable that some other incentive, as escape or exercise, replaced that of food. Blodgett reversed Sharp's procedure, by delaying the introduction of the incentive until after a preliminary practice series.

In human studies, the incentives have been of a more ideational sort. Reward and punishment of the cruder type have, however, been tried. And correlations have been made between the intensity of the punishment and its effect.

Rexroad used electric shock as punishment for errors in a multiple choice problem involving pressing the correct keys in response to color stimuli. He got a decrease in errors, and with it, a slowing up in speed of reaction, denoting an increased caution on the subject's part. Bunch introduced punishment by electric shock for errors into a maze learning problem. He found that the punished group learned with fewer errors, fewer trials and less time. He also found that the most effective learning occurred with those subjects who reported that the experience of the shock was only moderately intense. The relation of intensity of punishment to its effectiveness was systematically studied by Vaughn and Diserens. Unlike Bunch, who gave punishment only at the ends of the blind alleys, they constructed their maze so that punishment was received from all parts of the blind alleys. Four patterns were learned, each under a different strength of punishment, from none, through slight, moderate, to intense. They got fewest trials, fewest errors, and least time with slight punishment. Intense punishment, although producing quick reactions, delayed learning considerably.

McTeer used punishment for errors in a serial order learning experiment, in which the response consisted of pressing keys on a keyboard in a correct temporal order. The electric shocks resulted in a more cautious exploratory attitude of the learners. They took the same time to learn as a control group, but had less errors and required fewer trials. Increased intensity of shock tended to enhance the effect, within the limits studied.

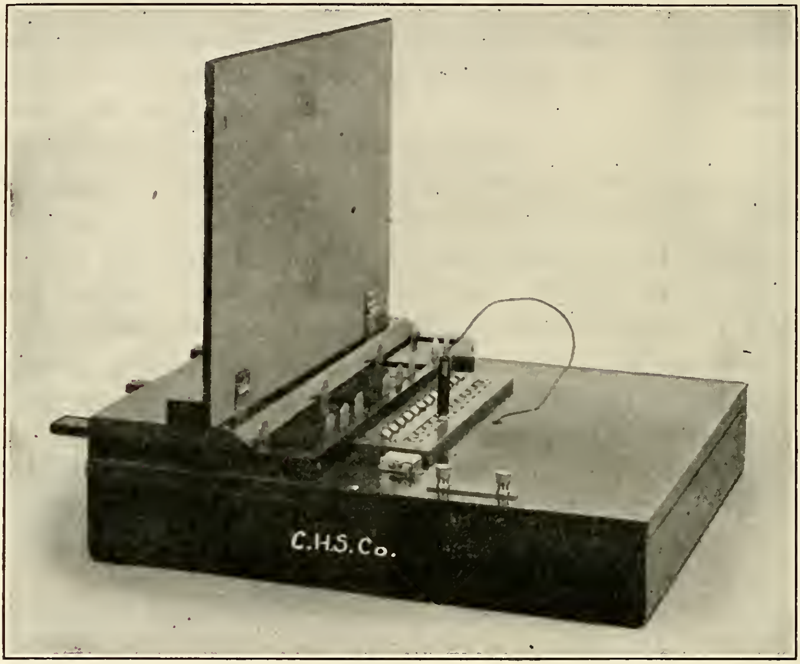


Fig. 66. Yerkes multiple choice apparatus
Courtesy C. H. Stoelting Co.

Very few studies of reward have been made, in which there were no complicating factors. Myers, in his study of practice effect in addition, substitution and cancellation, with school children, used reward in the form of credits and prizes. But he complicated it with rivalry and knowledge of results, so that the increased rate of improvement of the rewarded group might be due to the latter causes.

Praise and blame and encouragement and discouragement are social rewards whose influence on learning has been found great. Hurlock studied the relative effects of praise and reproof on the improvement of school children from 9 to 12 years, in arithmetic. Four groups, of 28 children each, were given five practice periods of 15 minutes each. One group was praised, another reproved, another ignored, and one group served as a control. The boys improved more with reproof than the girls, who gained most under praise, reacting adversely to reproof. The inferior members of the group responded better to praise than the superior. In general, praise was superior to reproof, regardless of sex or age.

A frequent type of incentive used in learning experiments is knowledge of results. The subject is informed of his previous record and is thus led to compete against himself. Reference has been made to its use by Book, and by Myers, in conjunction with other incentives. In order to judge of its effectiveness when operating alone, it is necessary to refer to studies in which it was the only incentive used.

For example, if the individual is working along with a group, and his results are published before the group the outcome cannot be attributed to knowledge of his own performance, as much as to the effect of rivalry and competition with the group. The experiment of Ross fulfils our requirements. He tested the improvement of 59 college students in a simple motor task of "tallying." He systematically varied the amount of information given in the following way: The subjects were divided into three sections. Section I had full information of their own progress, knew exactly what record they were making and how it compared with their previous record. Section II had only part information and merely knew who were above and who below the average. Section III was given no information. At the end of nine practice periods, the conditions were reversed, those without knowledge being given knowledge, and vice versa. During the first stage, the section with full information gained from

2.2% to 8.5% more than the sections with only partial information, and 4.5% to 12.6% more than the section with no information. Moreover there was no reversal after the conditions were shifted. This is contradictory to Book's results, but since Ross gave only three practice periods after his shift, it is impossible to predict what time would have brought out. The brightest subjects benefited most by motivation, making it appear that this sort of motivation, by self competition, tends to benefit the brighter students; whereas rivalry helps the duller, since they compare their efforts with their betters.

Out of knowledge of one's own results, and a comparison of these with social standards, come the attitudes of success or failure whose influence on learning is considerable. Lewin has brought out its relation to the strength of the subject's anticipation of the goal he is striving to attain. Success reinforces the goal idea, failure weakens it. McKinney found that when subjects of college-student level were given a stylus maze problem to learn, their learning time and errors were considerably increased when he suggested to them that they were not doing as well as their peers, and set too short a time for them to learn. The attitude of failure was accompanied by a tremendous emotional upset. He found an identical effect upon the learning of lists of nonsense syllables. Many more repetitions were required to learn.

Rivalry or competition is a social incentive of considerable strength. Sims has compared the relative influence of individual and group competition. In one experiment, 126 college students practiced substituting numbers for letters. They were divided into three groups. Group I had no motivation; Group II was subdivided into two groups which were pitted against one another; and the members of Group III were paired off against each other singly. The results show that Group I improved 102.2%; Group II, 109.9%, and Group III, 157.7%. Hence group rivalry is slightly better than none, but individual competition is superior to either.

ORGANIC FACTORS

For convencience of classification, organic factors may be divided into (a) sensory and neural conditions, including brain lesions, blindness, etc., and (b) general physiological conditions, including disease, fatigue, loss of sleep, glandular disturbance, drugs, and diet.

Neural and Sensory Conditions

Studies of the effects of cerebral destruction in animals show a definite relationship between the quantity of functional tissue and the capacity to learn. Lashley found a correlation of 0.86 ± 0.03 between the extent of brain injury and the number of errors made by rats in learning a maze. The relative contribution of the various cerebral areas is about equal. But with visual discrimination habits, except brightness discrimination, the visual cortex is essential. " In man, there seems to be a more definite restriction of learning by destruction of local areas. Improvement in every sort of activity seems possible after lesion in any locus (unless the total destruction of a projection area is involved), if the patient is not senile and can be properly motivated; but the rate of improvement in certain functions may be retarded. Thus the patient with severe aphasia seems to have much greater difficulty in forming verbal associations than in learning non-verbal material." The relation between lesions and retention will be considered later. " The symptoms of lesion in man emphasize the dynamic rather than the static in neural organization. It is not the specific reaction, but the mode of synthesizing activity which is affected by cerebral lesion."

Sensory conditions do not seem to be of great importance so far as learning is concerned. Studies of maze learning by the white rat show that it is possible to remove any sense organ without destroying a previously learned habit, or interfering with the formation of new habits.

This fact was originally explained as proprioceptive control, but Hunter has eliminated this factor in his double alternation temporal maze study, and concludes that control must be exercised by means of some central neural process symbolically representing the pattern.

Vertes studies the immediate memory of blind and seeing children. A group of 20 children, blind from birth, was compared with a group of 100 seeing children. Immediate memory for material presented auditorially was better for the blind than for the seeing group. Miles invented a high relief hand maze, constructed as a narrow raised path to be traced directly by the finger. He and Knotts then compared the learning efficiency in trials, errors, and time for two groups of 20 blind and two groups of 20 seeing subjects on this and an ordinary stylus maze. The blind subjects showed superior scores to the seeing though their range was wider. The more successful learners among the blind were those whose blindness occurred after 5 years. The blind tended to use the verbal method of learning.

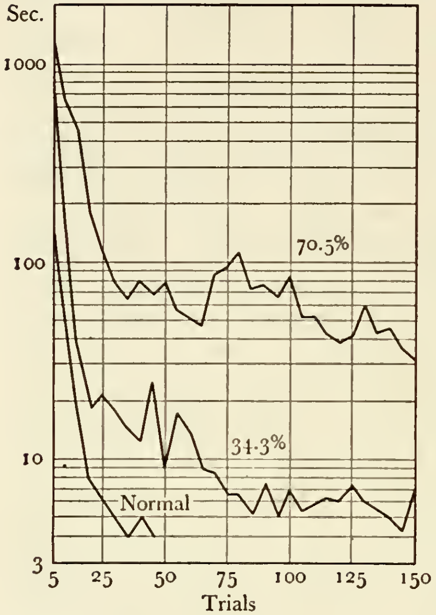


Fig. 67. Comparison of the learning curves of normal rats, and rats with intermediate and maximal cortical lesion

From Lashley in *Brain Mechanisms and Intelligence,* Univ. Chicago Press, 1929, p. 83, Fig. 19.

General Physiological Conditions

Fatigue. — Does ability to form associations deteriorate as a result of long periods of work at memorizing? And are the associations formed under these conditions retained as well? Oehrn had subjects learn lists of 12 digits for 2 hours and nonsense syllables for 1.5 hours. The numbers of nonsense syllables learned in the successive 15 minute periods were 1000, 855, 826, 754, 666, and 751. But Thorndike justly objects that the loss may have resulted from associative interference of the preceding on the later lists. Vogt worked seventy-five minutes daily for twelve days memorizing series of digits and of nonsense syllables. With the digits, there is an average loss of 7.5% during a day's work. With the nonsense syllables, the loss is 27%. This again may be due to associative interference, as is suggested by the far greater loss in the case of nonsense syllables. Morgan was interested in finding out whether material learned under fatigue conditions would be retained as well as the material learned before fatigue set in. He had 5 high school students, who knew no German, partially learn the English equivalents of 850 German words. The words were grouped into lists of 10 pairs each, and each list was exposed four times. They worked continuously for four hours. The average learning scores for the five successive sections of the work period were 3.62, 3.36, 2.99, 2.96, and 3.47 words respectively. Disregarding the end spurt, the loss is .66 words, or about 18%. Considering that the subjects were unpracticed, and therefore subject to a large practice improvement, the results indicate a small, though appreciable fatigue.

Loss of sleep. — Loss of two nights' sleep was shown to be detrimental to the learning and retention of nonsense syllables by Weiskotten. Thus the average time in seconds for learning 15 syllable lists before the insomnia period was 318. During the insomnia period it rose to 443, and subsequently it dropped to 233. Retention scores for the corresponding periods were 100, 181, and 76 respectively.

Drugs. — Some drugs affect learning deleteriously; others improve the function. Tobacco and alcohol belong to the former class; strychnine and probably caffeine to the latter. Hull, in a study of the effects of pipe smoking, found that non-smokers show a distinct loss in memory span efficiency as a result of smoking, which effect persists for some time after. The effect is reduced about one-half in the case of habitual smokers. But the efficiency of associative learning, i.e., associating geometrical figures with nonsense syllables, is reduced about 9% immediately after learning, for both smokers and non-smokers, with recovery occurring within an hour. Alcohol has been found deleterious by a long list of experimenters in both human and animal habit formation.

For example, Hollingworth employed a paired associate test of immediate memory for words. On each of the forenoons of two days the subjects learned four lists of 15 pairs of words under normal conditions. In the afternoon they learned the same number. One afternoon they were given a heavy alcohol dose, in the form of beer; the other afternoon none. The records show for the alcohol day an average of 6.2 items learned in the forenoon, and 2.5 in the afternoon. For the non-alcohol day, an average of 8.2 were learned in the morning and 7.5 in the afternoon. A recent study is that of Gustav Kurka, in which alcohol, in varying doses, was found to increase the number of errors and the variability of the records in the learning of nonsense syllables. Arlitt's study of the effect of alcohol on maze learning of rats is a classic. Not only were the alcohol-fed rats themselves inferior to the control group in learning but the effect carried over to their offspring for three generations.

Caffeine and strychnine, on the contrary, have a slightly beneficial effect. Tolman found that coffee, administered to subjects previous to the learning of word lists not only improved the learning and retention of the lists but rendered them less susceptible to retroactive inhibition. Meyer demonstrated the facilitative effect of caffeine administered in tea on the rate of improvement in shorthand.

Strychnine is also beneficial. For example, Lashley found that for maze learning in rats, subcutaneous injections of strychnine sulfate in 0.1 c.c. of water ten minutes before each day's run facilitated learning if given in large enough quantities, without altering retention scores. Caffeine administered in the same way caused a retardation in rate of acquisition, proportional to the size of the dose. Poffenberger tested the effect of medicinal sized doses of strychnine, taken into the stomach, on the efficiency of human subjects in a series of association tests, with negative results. The tests, however, did not get at learning directly, since they depended on previously formed associations; and Lashley found no effect of the drug on retention scores.

Diet and endocrine secretions.—The problem of control of diet in relation to learning efficiency has hardly been touched.

The studies on animals furnish practically the only evidence. The experiments on human fasting agree in showing either a drop or an increased variability in all mental processes during the fast, and a rise in efficiency, following the fast, above the pre-fast level. None of these, however, except Langfeld's study of Levanzin, tested learning directly.

Among the animal studies, Anderson and Smith compared the effects of three different diets on maze learning ability of rats. The diets were (1) a normal ration, (2) a gliadin diet, which keeps body weight in statu quo, and (3) a qualitatively normal but quantitatively deficient diet. Strange to say, the stunted rats learned more rapidly and retained better than the normally fed ones. When they were again realimented their behavior again returned to the level of the normal rats. Two possible factors in the situation are the greater hunger of the underfed rats, giving them a stronger maze running motivation, and the greater activity resulting from their small body weight.

The effect of vitamin deficiency has been tested by Fritz, by Frank, and by Tsai. Frank found that she could produce rickets by the vitamin D deficient diet; but she was unable to detect any appreciable effect on the learning ability of her rats, as compared with normal animals. Tsai, on the contrary, found that seventy day old rats who were nursed by mothers fed on a vitamin B deficient diet required from ninety-two to seventy-six trials to learn mazes which were learned by normal rats of the same age in thirty-one trials. At the time of running, both normal and stunted rats were being fed the same diet. Fritz, who began the vitamin B deficient diets on relatively mature rats, 90 to 100 days old, found no marked effect on maze performance. Typical experiments on endocrine hypo- and hyper-function are Blatz and Heron's study of anterior-pituitary and adrenal feeding and Rockwell's study of parathyroidectomy. Blatz and Heron compared three groups of rats, one of which was fed anterior-pituitary extract; one received adrenal cortex; and one group was given dried brain tissue as a control. The pituitary group showed superior ability in maze and problem box learning, as compared to the control rats. The adrenal group, on the contrary, was inferior. Though the differences are small, they gain significance from the consistency with which they appear in three different experiments. Rockwell could find no significant difference between the maze learning ability of parathyroidectomized and normal rats; but the retention of the operated animals was somewhat inferior, which probably accounts for the fact that they displayed less negative transfer in the learning of two antagonistic habits than normal animals.

INDIVIDUAL AND GROUP DIFFERENCES

When the records of individual subjects in any learning experiment are compared, wide differences in level of performance appear. Since these differences persist in spite of the equating of such factors as age, sex, training, etc., they must be classed as individual differences. The amount is a function of several factors, among which is the sort of learning material. For example, Lyon tested several groups on the learning of digits, syllables, words, prose, and poetry. The criterion was time necessary to learn one series. The ratios between the fastest and slowest learner in a group are given below, for each type of material: —

Number of Subjects	Ratios of Slowest to Fastest Learner				
	Digits	*Syllab.*	*Words*	*Prose*	*Poetry*
24	1:13	1:4	1:7	1:5	1:10

The average correlation between individual rates of learning for the different materials was .51.

Occasional cases have been reported of phenomenal memorizing. Often these subjects are otherwise subnormal in mental performance. A typical instance is that reported by Byrd, of a feeble-minded negro, 24 years of age, with a mental age of 8 or 9, who could give days for dates and dates for days between 1901 and 1924. His ability is attributed to the rote memorizing of a notebook which he kept. Frequently these phenomenal cases can be attributed to the use of some memory system or other. The ability is always limited to a restricted field.

The fact has been brought out by Thorndike and others that the discrepancy between the relative levels of different individuals tends to increase rather than decrease with practice in the function tested. Thus an individual occupying a relatively high initial position, relative to some other individual, will tend to increase the gap between his level and that of the poorer performer, the longer practice is continued.

Age Differences

A constantly augmented series of studies on the relation between age and learning ability establish beyond question that the memory function increases steadily to adulthood. The steepness of the rise differs for different materials and methods of measurement. Immediate memory with single exposure seems to give the greatest differences. Winch found a regular increase with age and school grade both, in the immediate graphical reproduction of groups of 12 consonants, presented visually or auditorially for 25 seconds.

Grade	2	3	4	5	6	7
Aver. age	7.25	8.25	9.67	10.75	11.2	13.0
% Reproduced	9.3	10.6	13.6	14.5	14.6	20.4

Lyon gives the average time in minutes to learn 5 series of materials, one each of digits, syllables, words, prose, and poetry. The table shows the relative learning times of college and high school students:

SUBJECTS	AGE	DIGITS	SYLLABLES	WORDS	PROSE	POETRY
20 College	22	5.45	12.00	10.7	11.15	9.85
60 High School	17	10.45	32.00	12.25	20.75	9.80

The table shows that adults learn all materials more rapidly except poetry.

Woodrow found, on comparing feeble-minded children of 14 years average chronological age and 9 years mental age with normal children of 9 years chronological and mental age, in sorting geometrical forms, that the curves of improvement had the same height and slope for both groups. This suggests that learning ability is a function of mental age rather than of physical maturation per se.

Ideational learning has been shown by Pyle to improve regularly and rapidly with age. When meaningful prose passages were studied for five minutes and the subjects were then asked questions about the main ideas contained in the passage, there was found to be a linear rise in ability with age, from a score of 4 at 9 years to a score of 28 at 17 years. The great increase in memory for meaningful material is significant, since it is mainly in this direction that adults excel children. The adult has a richer background from which to form logical associations and is more highly motivated toward this type of learning than the child, who would as soon learn by rote or learn relatively nonsensical materials.

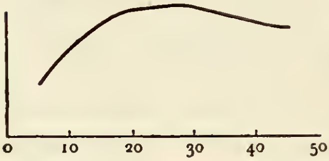


FIG. 68. Relation of memory to age of life

From Thorndike in *Adult Learning,* The Macmillan Co., 1930, p. 127, Fig. 8.

The problem of what happens to memorial capacity in older persons has recently been answered by an investigation of Thorndike's.

The assumption is commonly made that memory declines rapidly during middle life and on into old age. But the rate at which the decline takes place has been determined by Thorndike and his associates, as far as age 45. Figure 68 shows the curve from age 5 to 45. There is a steep rise as far as age 16, then a gradual negative acceleration to an asymptote at about 20. The subsequent decline begins about age 30 and is very gradual up to 45. At this point capacity has returned to about the sixteen year level. Thorndike therefore concludes that, "in general, nobody under forty-five should restrain himself from trying to learn anything because of a belief or fear that he is too old to be able to learn it."

Intelligence and Learning

Theoretically, the relation between intelligence and learning should be fairly close. It can be argued with reason that intelligence is largely a function of the ability to learn, and to solve problems. It is usually assumed that the problem solving type of learning utilizes intelligence or ingenuity more than memorial learning, which is assumed to be of the rote type. This question can be answered by comparing the correlations between learning and intelligence scores obtained from these two diverse sorts of material. Garrett gave eight tests of memory and learning to 200 college students of an average age of 19.4 years. The memory tests were (a) digit span, visual and auditory, (b) paired associates, visual and auditory, (c) logical memory for difficult prose, (d) Turkish-English vocabulary learning, (e) digit symbol learning, and (f) code learning. The first five are "memory tests," the last three are "learning" tests. The resulting scores were correlated individually with the Thorndike Intelligence Test scores of the subjects, and a multiple R was calculated between the Thorndike Test and the eight memory-learning tests. Although the individual tests all gave low correlations with intelligence scores, around .20, still, when the multiple coefficient was corrected for attenuation, it showed a correlation of approximately 0.60, indicating that the relationship between the learning function in general and intelligence is medium high. The corrected coefficient of correlation between the five *memory* tests and intelligence was 0.52, while the addition of the three learning tests raised it to 0.60.

There is evidence that problem solving efficiency such as is involved in maze performance and rational learning is more closely related to general intelligence. Peterson reports a correlation between his rational learning tests and estimated intelligence of the subjects of 0.86. Of the many studies of the relation between maze learning and intelligence, a typical example is that of Cox on the two story maze. This involves separate spatial orientations of the two hands, since the lower maze is revolved half or quarter way around with reference to the upper one. Intelligence was measured by the Thorndike Test. The correlations of time scores and intelligence scores range, for the different problems, from —0.59 ± 0.05 to —0.09 ± 0.09, the average being about —0.30. Significant differences in method of solving the maze were shown by groups chosen from three different levels of intelligence. The highest group used kinaesthesis, simple trial and error least, and rational planning, abstract schemes of solution most. As a matter of fact, correlation of individual scores on mazes with individual intelligence scores is a rather unreliable procedure, since Heron demonstrated that the reliability coefficient of the stylus maze is fairly low, and that chance contributes as much to the individual differences in score as does ability.

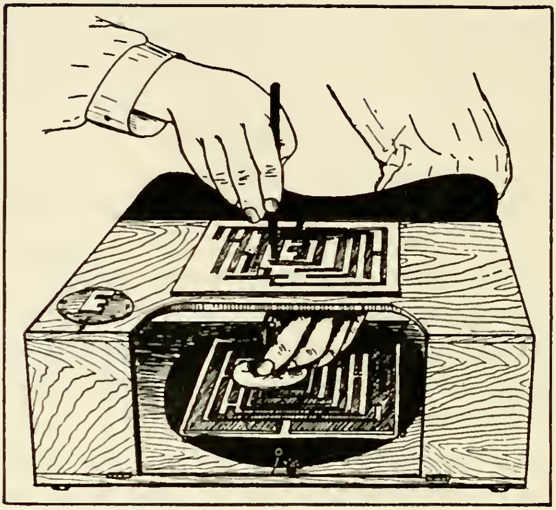


Fig. 69. Cox's two story maze

Courtesy C. H. Stoelting Co.

Some types of practice seem not to be correlated with general intelligence at all. Atkinson found that the ability of college students to improve with practice in card sorting, number code, substitution, etc., is only slightly related to intelligence scores.

REFERENCES

Achilles, E. M. Experimental studies in recall and recognition. *Arch. Psychol.*, 1920, No. 44, pp. 80.

Anderson, J. E., & Smith, A. H. The effect of quantitative and qualitative stunting upon maze learning in the white rat. *J. Comp. Psychol.*, 1926, 6, 337–359.

Atkinson, W. R. Limits of learning as related to intelligence and to mechanical speed. *J. Exper. Psychol.*, 1929, 12, 89–112.

Balken, E. R. Affective, volitional, and galvanic factors in learning. Ph.D. thesis, Univ. of Chicago, 1930.

Bills, A. G. The influence of muscular tension on the efficiency of mental work. *Amer. J. Psychol.*, 1927, 38, 227–251.

Blatz, W. E., & Heron, W. T. The effect of endocrine feeding upon the learning performance of white rats. *J. Exper. Psychol.*, 1924, 7, 291–311.

Book, W. F., & Norvell, L. The will to learn. *Ped. Sem.*, 1922, 29, 305–362.

Boswell, F. P., & Foster, W. S. On memorizing with the intention permanently to retain. *Amer. J. Psychol.*, 1916, 27, 420–426.

Bunch, M. E. The effect of electric shock as punishment for errors in human maze-learning. *J. Comp. Psychol.*, 1928, 8, 343–359.

Byrd, H. A case of phenomenal memorizing by a feeble-minded negro. *J. Appl. Psychol.*, 1920, 4, 202–206.

Carr, H. A. The influence of visual guidance in maze learning. *J. Exper. Psychol.*, 1921, 4, 399–417.

Carr, H. A., & Koch, H. L. The influence of extraneous controls in the learning process. *Psychol. Rev.*, 1919, 26, 287–293.

Cason, H. Specific serial learning; A study of remote forward association. *J. Exper. Psychol.*, 1926, 9, 299–324.

Cox, C. M. The intelligence factor in the solution of space problems with the two-story maze. *Amer. J. Psychol.*, 1928, 40, 542–561.

Ebbinghaus, H. Memory. (Trans. by Ruger and Bussenins.) New York: Teach. Coll., Columbia Univ., 1913.

Foucault, M. Les inhibitions extemes concomitantes au cours de la fixation des images. *L'Année Psychol.*, 1922, 23, 50–75.

Frank, M. The effect of a rickets-producing diet on the learning ability of white rats. *J. Comp. Psychol.*, 1932, 13, 87–105.

Fritz, M. F. Maze performance of the white rat in relation to unfavorable salt mixture and vitamin B deficiency. Ph.D. thesis: Univ. of Chicago, 1931.

Garrett, H. E. The relation of tests of memory and learning to each other and to general intelligence in a highly selected adult group. *J. Educ. Psychol.*, 1928, 19, 601–613.

Heron, W. T. Individual differences in ability vs. chance in the learning of the stylus maze. *Comp. Psychol. Monog.*, 1924, 2, No. 8,

Hollingworth, H. Psychological influence of alcohol. *J. Abn. & Soc. Psychol.*, 1923, 18, 204–237; 1924, 18, 317–333.

Hull, C. L. The influence of tobacco smoking on mental and motor efficiency. *Psychol. Monog.*, 1924, 33, No. 150, pp. 160.

Hunter, W. S. A further consideration of the sensory control of the maze habit in the white rat. *Ped. Sem.*, 1930, 38, 3–19.

Hurlock, E. An evaluation of certain incentives used in school work. *J. Educ. Psychol.*, 1925, 16, 145–159.

Judd, C. H. Practice without knowledge of results. *Psychol. Rev. Monog. Suppl.*, 1905, 7, No. 29, 185–194.

Koch, H. L. The influence of mechanical guidance upon maze learning. *Psychol. Monog.*, 1923, 32, pp. 112.

Kurka, G. Die Wirkung verschiedener alkolischer Getränke auf geistige Leistungen. *Zsch. f. angew. Psychol.*, 1928, 30, 430–532.

Langfield, H. S. On the psychophysiology of a prolonged fast. *Psychol. Monog.*, 1914, 16, No. 71, pp. 62.

Lashley, K. S. Brain mechanisms and intelligence. Chicago: Univ. of Chicago Press, 1929.

Lashley, K. S. The effects of strychnine and caffeine upon the rate of learning. *Psychobiol.*, 1917, 1, 141–169.

Lewin, K., & Hoppe, F. Erfolg und Misserfolg. *Psychol. Forsch.*, 14, 1–62.

Lowes, H. H. The influence of gradual removal of mechanical guidance in maze learning. A.M. thesis: Univ. of Chicago, 1930.

Ludgate, K. The effect of manual guidance upon maze learning. *Psychol. Monog.*, 1924, 33, Pp. 65.

Lyon, D. O. The relation of quickness of learning to retentiveness. *Arch. Psychol.*, 1916, 5, No. 34.

McKinney, F. Certain emotional factors in learning and efficiency. Ph.D. thesis: Univ. of Chicago, 1931.

McTeer, W. A study of certain features of punishment in serial learning. *J. Exper. Psychol.*, 1931, 14, 453–476.

Meyer, M. F. Alcohol, tobacco, and tea: the efficiency under drugs as derived from the learning equation. *Amer. J. Psychol.*, 1923, 34, 501–510.

Miles, W. R., & Knotts, J. R. The maze learning ability of blind compared with sighted children. *Ped. Sem.*, 1929, 36, 21–50.

Morgan, J. J. B. The effect of fatigue on retention. *J. Exper. Psychol.*, 1920, 3, 319–333.

Morgan, J. J. B. The effect of sound distraction upon memory. *Amer. J. Psychol.*, 1917, 28, 191–208.

Myers, G. C. A study in incidental memory. *Arch. Psychol.*, 1913, 21, No. 26, pp. 108.

Oehrn, A. Experimentelle Studien zur Individual-psychologie. *Psychol. Arbeiten*, 1895, 1, 92–151.

Perrin, F. A. C. Conscious analysis versus habit hierarchies in the learning process. *J. Comp. Psychol.*, 1921, 1, 287–308.

Peterson, J. The effect of attitude on the immediate and delayed reproduction. *J. Educ. Psychol.*, 1916, 7, 523–532.

Poffenberger, A. T. The effects of strychnine on mental and motor efficiency. *Amer. J. Psychol.*, 1914, 25, 82–120.

Pyle, W. H. Nature and development of learning capacity. Baltimore: Warwick and York, 1925.

Rexroad, C. N. Administering electric shock for inaccuracy in continuous multiple choice reactions. *J. Exper. Psychol.*, 1926, 9, 1–18.

Rockwell, J. G. Thyro-parathyroid deficiency as related to learning. Ph.D. thesis: Univ. of Chicago, 1931.

Ross, C. C. An experiment in motivation. *J. Educ. Psychol.*, 1927, 18, 337–346.

Russell, J. T. Relative efficiency of relaxation and tension in performing an act of skill. *J. Gen. Psychol.*, 1932, 6, 330–343.

Shellow, S. M. Individual differences in incidental memory. *Arch. Psychol.*, 1922, No. 64, pp. 53.

Sims, V. M. The relative influence of two types of motivation on improvement. *J. Educ. Psychol.*, 1928, 20, 480–484.

Smith, M., & McDougall, W. Some experiments in learning and retention. *Brit. J. Psychol.*, 1919–20, 10, 199–209.

Spencer, L. T. Effects of practice without knowledge of results. *Amer. J. Psychol.*, 1923, 34, 107–111.

Stern, L. W. Die Aussage als geistige Leistung und als Verhörsproduct. Leipzig: Barth, 1904. S. iv + 147.

Stroud, J. B. The role of muscular tensions in stylus maze learning. *J. Exper. Psychol.*, 1931, 14, 606–631.

Sullivan, E. B. Attitude in relation to learning. *Psychol. Monog.*, 1927, 36, No. 169, pp. 149.

Thorndike, E. L. Adult learning. New York: Macmillan, 1928. Pp. x + 335.

Tolman, E. C. Retroactive inhibition as affected by conditions of learning. *Psychol. Monog.*, 1918, 25, No. 107.

Triplett, N. The dynamogenic factors in pace-making and competition. *Amer. J. Psychol.*, 1898, 9, 507–533.

Tsai, L. S., & Maurer, S. Vitamin B. deficiency and learning ability. *J. Comp. Psychol.*, 1930, 11, 51–62.

Vaughn, J., & Diserens, C. M. The relative effects of various intensities of punishment on learning and efficiency. *J. Comp. Psychol.*, 1930, 10, 55–66.

Vertes, J. O. Das Gedächtnis der Blinden. *Arch. f. d. ges. Psychol.*, 1920, 39, 214–231.

Vogt, R. Ueber Ablenklarheit und Gewöhnungsfähigkeit. *Psychol. Arbeiten*, 1899, 3, 62–201.

Waters, R. H. The influence of tuition upon ideational learning. *J. Gen. Psychol.*, 1928, 1, 534–549.

Waters, R. H. The influence of large amounts of manual guidance upon human maze learning. *J. Gen. Psychol.*, 1930, 4, 213–228.

Weiskotten, T. F. On the effects of the loss of sleep. *J. Exper. Psychol.*, 1925, 8, 363–380.

Winch, W. H. Immediate memory in school children. *Brit. J. Psychol.*, 1904, 1, 127–134; 1906, 2, 52–57.

Woodrow, H. Practice and transference in normal and feeble-minded children. *J. Educ. Psychol.*, 1917, 8, 85–96, 151–165.

Woodworth, R. S. A revision of imageless thought. *Psychol. Rev.*, 1915, 22, 1–27.

CHAPTER XIII

TRANSFER OF TRAINING

TO WHAT extent does training in a given habit exert an influence on the formation of subsequent habits? This is the problem of transfer of training, and it applies to all kinds of learning, from the perceptual motor acquisition of skills and the memorizing of nonsense syllables to the solution of ideational problems. The question has received most attention from educators, since the entire theory of educational procedure rests upon the assumption of a wide transferability of habits and training. The widespread revolt against the doctrine of formal discipline has completely revolutionized educational curricula in recent years, and the impetus for the revolt came from laboratory experiments of psychologists on the transferability of learning.

From the standpoint of systematic psychology, this topic of transfer of training is only a phase of the broader problem of the utilization of what is learned, in reacting to subsequent situations. Probably there are always differences of some sort between the situation in which a thing is learned and the situation in which it is later used. The problem is one of determining how much and in what ways the situation may vary, and still be reacted to in terms of the past learning. It is a part of the process of generalization and concept formation which is considered an essential feature of abstract thinking or reasoning. Generalization and concept formation are discussed later in connection with the topic "Thought."

The learning of a given habit might influence the efficiency of learning of a subsequent habit in a positive direction, or in a negative direction, or not at all. Consequently transfer is spoken of as positive, negative, or zero. Negative transfer is also called interference, and may be associative or reproductive, depending upon whether interference is exerted upon the formation of new associations or on the revival of old ones. The latter type, also known as retroactive inhibition, will be discussed in connection with retention.

The clearest exposition of these transfer studies can be made from the point of view of their historical development.

STUDIES OF CROSS EDUCATION

Psychologists were early concerned with the problem of transfer of skill from one side of the body to the other, on the ground that the two sides of the body are controlled by opposite hemispheres of the brain which communicate with one another only through the rather limited system of commissural fibers. Yet practice with the right hand improves performance with the left hand. And the same cross education occurs in the case of other bilaterally symmetrical members. In an early experiment at Yale, reported by Scripture, in which Miss Smith was both subject and experimenter, the phenomenon was investigated in the following way. The subject tested both left and right hands initially by 20 trials in inserting a needle-like stylus into a hole in a plate .1285 inches in diameter. Thereafter, the right hand was given 200 trials per day for 10 days, and the left hand was then retested. When contacts with the side of the hole were scored as errors, there was a positive transfer gain of 26% in accuracy for the left hand as a result of practicing the right hand. Swift's results on ball tossing confirm the foregoing. He had four subjects practice keeping two balls going in the air with the right hand; they were given ten exercises per day, each consisting of throwing till a miss occurred. Practice was continued till the subjects had a record of 1000 successful catches for 2 days. Before and after the training, the left hand was tested by ten trials. Thereafter it was given further training to determine the curve of progress. The results show an increased skill of the left hand caused by the right hand practice; also, the subsequent learning curve for the left hand showed more rapid improvement than that of the right.

Starch introduced the star-tracing, mirror-drawing experiment which is now used so widely to demonstrate cross education. He had his subjects trace the first half of a six-pointed star with the left hand, then trace ten complete outlines with the right hand, then another half outline with the left. Errors and time were the criteria. The subjects showed an average left hand improvement of 49%, and a right hand improvement of 53%. The left hand may be said to have profited to the extent of 90% of the gain made by the right.

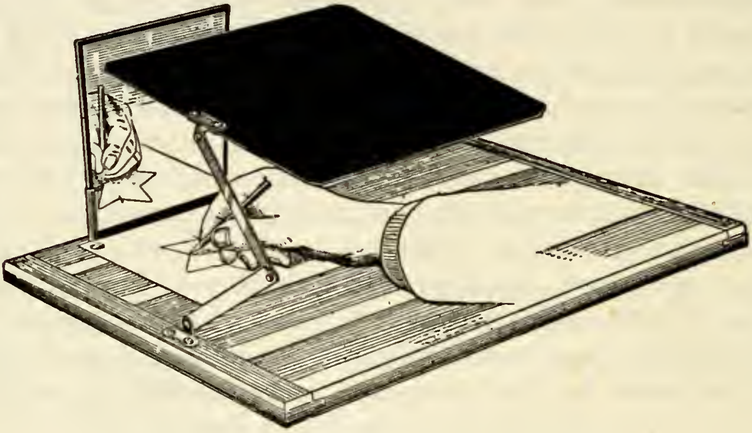


FIG. 70. Mirror star tracing board

Courtesy C. H. Stoelting Co.

Norcross, in a recent experiment on the operation of adding machines, obtained improvement of from 14 to 48% in the left (idle) hand after practice with the right hand which improved it from 16 to 50%. In two cases the idle hand improved more than the practiced one. He explains the effect as due to four things; changing emotional attitude, better concentration, less fatigue, and increased efficiency in reading the numbers. No doubt all these helped. But the size of the gain in such experiments seems to compel the hypothesis that when the left side of the brain is being exercised, the right is simultaneously exercised, or that the control pattern is general, and independent of either hemisphere alone. Lashley's results from unilateral destruction of the motor cortex are relevant.

STUDIES OF TRANSFER IN MEMORIZING

THE old "faculty" psychology taught that memory was a general faculty of the mind, capable of being exercised like a muscle, and that improvement in memory as such applied to all materials and situations. In the revolt against this theory, many experiments have been performed, the net results of which are somewhat contradictory. Certain studies show a clearly positive transfer. Winch, using 13-year-old school girls as subjects, tested them in memorizing historical material for 10 minutes. He then divided them into two groups, one of which practiced memorizing poetry for 2 weeks, while the other group worked on sums. He then retested them, and found an average positive transfer increment of ten points for the experimental group. Fracker studied the transfer effect of one kind of memorizing on six other kinds. He trained eight subjects in memorizing given orders of four tones. Before and after this training period, these subjects, and a control group of four subjects, were tested in memory for poetry, order of 4 shades of gray, order of 9 tones, 9 shades of gray, 9 geometric figures, 7 numbers, extent of arm movement, and 4 tones. The gains in per cent of correct responses for the experimental and control group are as follows:

MEMORY FOR	EXPERIMENTAL GROUP	CONTROL GROUP	TRANSFER
Poetry	7%	2%	5%
Order of 4 shades of gray	36	4	32
Order of 9 tones	22	11	11
Order of 9 shades of gray	19	10	9
Order of 4 tones	10	2	12
Order of 9 geometric figures	13	8	5
Extent of arm movement	0	1	1

It is interesting to note that the transfer effect was fairly marked when the tasks involved similar procedures, as memorizing orders of tones and memorizing orders of shades of gray. But much less transfer, if any, is evident where the tasks differ radically from the original, as memorizing poetry and extent of arm movements.

Other studies show practically no transfer, or extremely variable results. An example is William James's classic experiment on the learning of poetry. First, 158 lines of Victor Hugo's " Satyr " were learned, by himself and four students, in an average time of 131.8 minutes; then thirty-eight successive practice periods were spent committing passages from " Paradise Lost," and finally 158 different lines from the " Satyr " were memorized. The time was 151.5 minutes, or about 20 minutes longer than before practice. Yet anyone who has experimented with nonsense syllables knows that there is an extremely rapid improvement in rate of learning from list to list. In fact, naïve subjects who have never learned such lists before, frequently cut their learning time in two by the time they have committed four or five such lists. Much of this transfer effect consists in familiarizing the subject with apparatus and material.

Transfer of Modes of Procedure

Ebert and Meumann found that training in nonsense syllable learning tended to improve the learning of letters, numbers, words, and vocabularies, passages of prose and poetry, and meaningless visual characters to a certain degree but far less than was the effect of nonsense syllables on themselves.

Any number of studies, both animal and human, demonstrate this sort of transfer. Of the animal studies, Wylie's is typical. He taught several groups of rats to make a negative response either to a light, a sound, or an electrical stimulus. The various groups were then taught to make a negative response to some other one of these various stimuli. The problem box was so arranged that the stimulus could be given anywhere along the path and the animal must turn about and go the other way. The results always give evidence of positive transfer. For example, those who transferred from light to sound took 153 trials and 10 series; whereas those who learned sound first took 526 trials and 35 series. Webb and Wiltbank both report positive transfer in maze learning by rats. Out of ten pairs of mazes, Webb found an average saving for the second of the pair, of 59% in trials, 65% in errors, and 68% in time. In human subjects the saving from one stylus maze to another averaged 33% in trials, 62% in errors and 58% in time.

Wiltbank corroborated Webb's findings, and in addition tested transfer throughout a series of mazes, and found that having learned more than one previous maze is not always an advantage. He also discovered that, provided the first maze is only partially learned, say 2 to 4 trials, the transfer may be negative in terms of trials and errors, though 16 or more trials give positive transfer.

On the human side, studies by Thorndike and Woodworth are instructive. In one, they tested the ability of six subjects to estimate areas of different shapes, before and after training in the judgment of rectangles. Throughout the training, they were kept informed of their errors. The results obtained are as follows:

AVERAGE ERRORS BEFORE TRAINING	AVERAGE ERRORS AFTER TRAINING	TRANSFER
18%	14%	+4%

In the case of two of the subjects, however, there was a slight negative transfer.

The same investigators trained five subjects to react to reading matter by marking out all words that contained both *e* and *s*. Before and after this training the subjects were tested in similarly marking out words containing other pairs of letters, *s* and *p*, etc., seven of them in all. The first four appeared in reading matter similar to that read in the training series, whereas the latter three appeared in material which differed in length of lines, size of type, etc., from the first. The average per cent gain from transfer for the first four pairs was 17%; that for the last three was 31%. When these authors trained subjects in estimating the lengths of lines $\frac{1}{2}$ to $1\frac{1}{2}$ inches long, and then tried them on the estimation of lengths of lines 6 to 12 inches, they obtained no transfer. Evidently the mode of procedure in such estimations differs significantly with absolute length.

Where actual rules of procedure of general applicability can be set up, transfer is positive. Coover and Angell trained four subjects to give discriminatory reactions to sound by means of seventeen exercises of forty judgments each, over a period of 57 days. Before and after this training, they were tested in discrimination of shades of gray by means of three series of 35 judgments each, on three successive days. The average amount of transfer as measured against a control group was 8%.

Puzzle solving offers an ideal sort of problem for the study of transfer. Ruger, in his study, had the same subjects solve several puzzles in succession. Where there was the possibility of putting into words or of formulating the essential factors in the solution of the earlier puzzles, the benefit of this formulation was more likely to be carried over. But it was essential that the similar feature should be explicitly recognized, and it could easily escape attention, provided some other feature caught and held the attention first. This point is also well illustrated in the experiment of Judd, in which he set a group of 50 boys to shooting at targets located under water. When they had reached a satisfactory degree of proficiency in hitting the under-water targets, he then divided the group into two sub groups. One of these was taken aside and instructed in the physical principle of refraction. The other group was told nothing. The targets were then shifted and both groups again practiced shooting. At first the two groups had about an equal number of errors, but, after a while, the boys who possessed the general principle forged ahead of the others.

THEORIES OF TRANSFER

ALONG with the experimental findings, theories of the nature of transfer have developed. One of the earlier formulations is that attributed to Thorndike, known as the identical elements theory. It assumes that the degree of transfer from one task to another is a function of the number of identical elements in the two situations. Now the term " elements," here used, might conceivably be interpreted in several ways. It might refer to the stimuli, and mean that the materials learned contained identical elements. Or it might refer to the neural processes involved, meaning that identical neural elements or neural " bonds," i.e., associative connections, are utilized. Still another possible interpretation would be that a logical identity is meant. Which one of these we choose determines whether we are applying the law on a descriptive or explanatory level. Since little is known about the nature of the control processes involved, and since grave doubt attaches to the concept of isolated neural bonds or to the assumption that identity of stimulus features implies identity of neural elements, it seems safer to interpret the law on the descriptive level only.

However, that identity is the only factor involved seems improbable. All cases in which things are pronounced " similar " imply a transfer in thought from one to the other. Yet not all cases of similarity can be shown to involve unambiguously the principle of partial identity.

It is doubtful whether the principle of similarity can be trusted to operate in cases where the subject's training is not such as to make the similarity explicit to him.

The most important objection to the law of Thorndike is that it applies only to cases of positive transfer, where there may be assumed to be identical features, and to cases of zero transfer where such identical features are lacking. But it fails completely to explain the frequent cases of negative transfer, where the learning of one habit interferes with the efficiency of acquisition of a subsequent one. No law of transfer which leaves negative transfer unaccounted for is satisfactory.

CASES OF NEGATIVE TRANSFER

THOUGH the earlier studies reported only positive or zero transfer, yet cases of negative transfer have appeared. Typical of the animal studies are those of Hunter and Pearce.

Hunter, using a T shaped discrimination box, required a group of 16 rats first to learn to turn to the right when given a light stimulus and to the left when no stimulus was given. He then reversed the problem and had them learn to turn to the left for the stimulus and to the right when it was absent. Mistakes were punished. The rats were given 10 trials per day and the habit was considered learned when they ran 95% correct trials for two days. He found that whereas the average number of trials necessary to master the first habit was 286, the second habit required 603 trials. The negative transfer effect was therefore over 200%. Pearce corroborated these results. In her first test the average number of trials required was 165; and, of the eight rats, only one had learned the second habit after an average of around 1000 trials.

Typical human studies are the following:

Culler used a card sorting experiment in which subjects sorted cards into pigeonholes labelled with sample cards. Two sets of pigeonholes having different arrangements of the sample cards were used. One group of subjects sorted alternately according to the two different arrangements. Another group worked continuously at the same arrangement. The experimental group made 16 sortings per day for 6 days, while the control group made 8 sortings per day for 6 days. The average time per sorting was reduced from 113 to 72 for the experimental group, and from 119 to 57 for the controls. That interference of habits caused this difference is shown by the fact that on each day the experimental group made their best record on the first trial, before the interfering habit was performed, whereas the control group made their best record on the last trial each day.

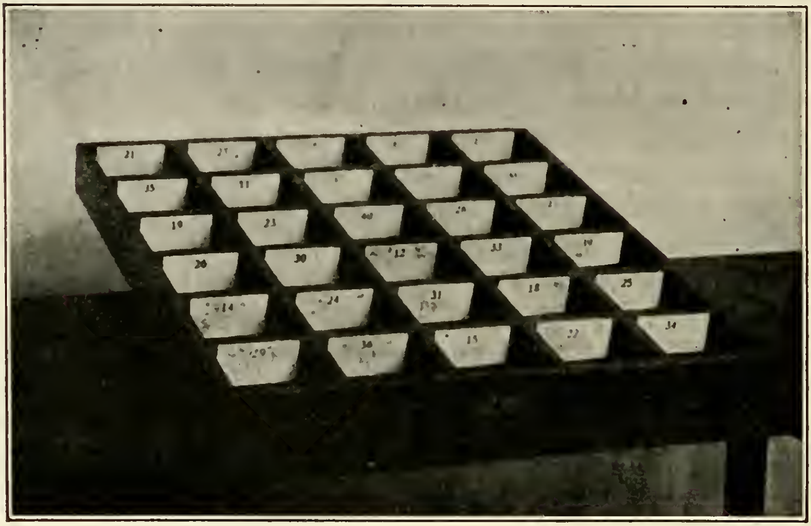


FIG. 71. Card sorting experiment
Courtesy C. H. Stoelting Co.

Poffenberger devised an experiment in which he systematically varied the degree of similarity between the tasks all the way from near identity to absolute antagonism. In this way he could determine whether similarity invariably causes positive transfer. He trained four subjects, during nine days, one hundred times in each of the following tests: color naming, opposites, number checking, and addition. Before, and after this training, he tested these four subjects, together with a control group, five times in each of the following tests: form naming, adjective noun, number group checking, and calculation. He obtained the following results:

(a) Color to form naming: two cases of negative, two zero, no positive transfer.
(b) Opposites to adjective noun — no positive transfer.
(c) Cancellation of three and five separately to cancelling them in groups: small positive transfer.
(d) Cancellation of three and five to four and seven: — zero transfer.
(e) Addition to subtraction: zero transfer.
(f) Addition to multiplication: negative transfer.
(g) Addition to division: zero transfer.

The frequency of appearance of interference and the paucity of positive transfer led Poffenberger to a complete reformulation of the law of Thorndike which would include negative results. He felt that the interference arose where it was necessary to break up previously established associational bonds in order to establish the new habit. He therefore amended the law as follows: The amount of positive transfer is proportional to the similarity of the two tasks, except where this similarity means that the bonds established in the first habit must be disrupted before the second habit can be formed; in the latter case negative transfer will result.

The theory is unsatisfactory in that it fails to enable one to predict whether negative or positive transfer will occur. For the only criterion of whether bonds must be broken or not is the presence or absence of negative transfer. A somewhat more satisfactory hypothesis has been advanced by Bruce and Wylie.

THE IDENTITY OF STIMULI OR RESPONSES

As a result of his own experiment, previously referred to, in which he taught rats to make a negative response to light, sound, or electricity, and then shifted the stimulus and got positive transfer, Wylie concluded that it was because he changed the *stimulus* but left the *response* the same. Hunter had obtained negative transfer because he had shifted the *response* but left the *stimulus* the same; i.e., the stimulus light had first called forth a response of turning left, and then was associated with a response of turning right. Following out this line of reasoning, Bruce set up an experiment on human subjects in which he was able directly to compare the two following transfer situations:

I From S_1–R_1 to S_1–R_2
II From S_1–R_1 to S_2–R_1

where $S_1 =$ one stimulus, $R_1 =$ one response, $S_2 =$ a different stimulus, and $R_2 =$ a different response. The first situation then would be one in which the stimulus is kept constant and the response varied. The second situation would be one in which the response is kept constant and the stimulus is varied. He used lists of paired associate nonsense syllables, and presented them in two ways: (1) where the subjects first learned to associate the items of List A with List B, and then later to associate List A with List C, and (2) where they first learned to associate the items of List A with those of List B and then later to associate those of List C with List B. He found that the first method produced negative transfer, while the other produced positive transfer. The amount, in each case, was a function of the number of repetitions given to the first pair of lists, i.e., the degree of integration of the initial habit. A high degree of integration tends to increase the amount of positive and decrease the amount of negative transfer. If we stop to think, this result is quite logical. If one has established a connection between a given stimulus and a given response, then *that* response rather than any other is bound to follow the presentation of that stimulus. And before that stimulus could be made to call out any different response, it would be necessary to weaken that connection. On the other hand, if one has established a connection between a given stimulus and a given response, that need not in any way interfere with the establishing of connections between that response and any number of other stimuli. Thus one could teach a dog to bark when a whistle blew and this would not interfere with teaching him to bark when one called his name.

It is evident that we now have a better basis for interpreting Poffenberger's theory, since we can now state the situations under which previously established bonds *must be broken* or not, and hence whether negative or positive transfer will result.

REFERENCES

Bruce, R. W. Conditions of transfer of training. *J. Exper. Psychol.*, 1933, 16, 343–361.

Coover, J. E., and Angell, F. General practice effect of special exercise. *Amer. J. Psychol.*, 1907, 18, 327–340.

Culler, A. J. Interference and adaptability. *Arch. of Psychol.*, 1912, 21, No. 24.

Ebert, E., and Meumann, E. Ueber einige Grundfragen der Psychologie der Uebungsphänomene in Bereiche des Gedächtnisses. *Arch. f. d. ges. Psychol.*, 1905, 4, 1–232.

Fracker, G. C. On the transference of training in memory. *Psychol. Monog.*, 1908, 9, No. 2.

Hunter, W. S. Habit interference in the white rat and in human subjects. *J. Comp. Psychol.*, 1922, 2, 29–59.

James, W. Principles of psychology. New York: Holt, 1890, pp. 666.

Judd. C. H. The relation of special training to general intelligence. *Educ. Rev.*, 1908, 36, 28–42.

Lashley, K. S. Studies of Cerebral Function in Learning. VI. The theory that synaptic resistance is reduced by the passage of the nervous impulse. *Psychol. Rev.*, 1924, 31, 369–375.

Norcross, W. H. Experiments on the transfer of training. *J. Comp. Psychol.*, 1921, 1, 317–364.

Pearce, B. D. A note on the interference of visual habits in the white rat. *J. Animal Behav.*, 1917, 7, 169–177.

Poffenberger, A. T. The influence of improvement in one mental function upon other related processes. *J. Educ. Psychol.*, 1915, 6, 459–474.

Ruger, H. A. The psychology of efficiency. *Arch. Psychol.*, 1910, 2, No. 15.

Scripture, E. W., Smith, T. L., and Brown, E. M. On the education of muscular control and power. *Stud. Yale Psychol. Lab.*, 1894, 2, 115.

Starch, D. A demonstration of the trial and error method of learning. *Psychol. Bull.*, 1910, 7, 20–23. Also, Transfer of training in arithmetical operations. *J. Ed. Psychol.*, 1911, 2, 306–310.

Swift, E. J. The acquisition of skill in typewriting. *Psychol. Bull.*, 1904, 1, 295–305.

Thorndike, E. L. Educational psychology. New York: Lemcke and Buechner, 1903, pp. 80–81.

Thorndike, E. L., & Woodworth, R. S. The influence of improvement in one mental function upon the efficiency of other functions. *Psychol. Rev.*, 1901, 8, 247–261, 384–395, 553–564.

Webb, L. W. Transfer of training and retroaction. *Psychol. Monog.*, 1917, 24, No. 3.

Wiltbank, R. T. Transfer of training in white rats upon various series of mazes. *Behav. Monog.*, 1919, 4, No. 1.

Winch, W. H. The transfer of improvement in memory in school children. *Brit. J. Psychol.*, 1908, 2, 284–293.

Wylie, H. H. An experimental study of transfer of response in the white rat. *Behav. Monog.*, 1919, 3, No. 5.

Section B—Retention and Recall

CHAPTER XIV

RETENTION AND FORGETTING

AS HAS been pointed out, the functions of retention and recall are closely related but not identical. Recall is dependent upon retention in some form, but retention does not guarantee reinstatement. Inability to recall material is no proof that the material has been permanently forgotten. There may be some factor present at the moment which is preventing recall from taking place.

However, the proposition, which has been advanced by certain theorists, that nothing is ever really permanently forgotten, is manifestly absurd, even though we cannot possibly test its validity. The ultimate test of retention is some form of reinstatement. And when all tests of reinstatement fail, we are compelled to assert that the material is, at least functionally, lost or permanently forgotten.

Retention may be defined as the persistence of impressions over a period of time. The neural impressions created by the act of learning are assumed to remain intact for a certain length of time. Theoretically, an impression once received should never be lost, except for the changes which living tissue must undergo from metabolism. Hence any loss in retention must be accounted for in terms of active disruptive factors.

The opposite tendency, that is toward loss of impressions, is forgetting, and it is to the theories of forgetting that we must look for an explanation of the relative efficiency of retention under different conditions.

THEORIES OF FORGETTING

Neurological

DECAY of neural impressions. The assumption underlying the neural decay theory is that definite patterns of some structural form are impressed upon the nervous system, and that these patterns are subject to decay if not exercised. For example, assuming learning to consist in reduction of synaptic resistance in certain neural systems, then the theory would suppose that the resistance gradually increases with disuse of the system. It has been suggested that forgetting resembles the action of a catalytic agent, and that some form of catalysis may actually be going on. In fact the resemblance of the curve of forgetting to a catalytic curve will appear later.

Obviously, the theory is under the necessity of explaining certain things. Why are some impressions never forgotten? It is common for aged persons to revive memories of childhood; or, on becoming delirious, to live in a childhood phantasy and call the persons about them by the names of former relatives long since dead. There is the case of Professor Warren's father, who, on receiving a telegram inviting him to his fiftieth college reunion, commenced to recite his senior oration, and did so with few errors, though he hadn't thought of it in fifty years. Titchener recited the poem " The Morning of Christ's Nativity " with few promptings, at age 60, not having rehearsed it since he learned it at eight years of age.

Not so difficult is the necessity of explaining why new associations fade faster than old ones, and why an equal amount of practice benefits old associations most. It would follow from the catalytic theory, that neural decay would follow a negatively accelerated course, and that impressions which outlived the early period would be forgotten at a much slower rate.

Lesions. — Many instances of amnesia can of course be explained in terms of specific changes in the nervous system caused by injury, disease, and extirpation after learning has occurred. Lashley, in his work with rats, found that the number of trials necessary to relearn, after cerebral insult, a habit which had been acquired previous to the operation, was roughly proportional to the extent of the lesion. In human subjects, there is more evidence for restricted loss with localized lesions, but even here it seems to be memory systems of a broad general order which are affected, rather than specific bodies of material.

Psychological

Lack of Proper Stimulus. — If it is borne in mind that every habit, which includes memories of course, is a stimulus-response connection, then it is clear that the operation of the habit requires the presence of the stimulus. However, as Hollingworth's principle of redintegration emphasizes, it is not necessary for the entire stimulus situation to be re-presented in order to set off the habit. One element in the total situation may be enough to arouse the response which was originally given to the entire complex. But the problem of determining what proportion of the total stimulus-situation, or what specific elements in that situation constitute a minimum requirement, is an experimental one. And experimental evidence points to the theory that any shift whatsoever in the total stimulus pattern exerts some inhibitory effect on recall. An oft quoted illustration is the inability to speak the name of a person with whom one is perfectly familiar, provided that person is met in an entirely new environment. Another is the case of the missionary who, after living some years in China, had learned to speak Chinese with fluency. On returning to America, he neglected to practice Chinese, speaking only English, and soon found that his ability to talk in Chinese had disappeared. When, however, he returned to the Orient, the language habit was reinstated by the presence of familiar stimuli with which he was surrounded and under which he had originally acquired it.

Interference or Retroactive Inhibition. — Any activity engaged in between learning and recall tends to interfere with the retention of a habit. The ideal condition is a period of mental inactivity. But the effect is much more pronounced, when the interpolated activity is similar to the original. Hence it is assumed that elements of the original habit become incorporated into the second habit, with the consequent disintegration of the original habit.

Repression and Suppression. — The doctrine of conscious, voluntary inhibition of unpleasant impressions from the mind has been supplemented by Psychoanalysis, with a theory of the unconscious repression of the unpleasant or socially inacceptable. The repressed material is supposed to be cut off from conscious recall, but not to be lost. The metaphysics of Psychoanalysis is admittedly confused, with reference to the form in which the repressed material is stored. But the essential assumption, that material is forgotten *because* it is unpleasant or socially inacceptable, can be subjected to experimental test.

Poor Initial Fixation. — The failure to thoroughly fixate material in the original learning has been pointed out as one cause of forgetting. According to the original explanation of retroactive inhibition offered by Müller and Pilzeker, the effect was attributed to an interference with the perseverative or setting-in process which was supposed to follow immediately on the cessation of active practice, and to persist for a short time. Any mental activity engaged in during this setting-in process was assumed to disrupt the process, and thereby prevent the formation of the habit pattern. Experimental evidence is largely against this theory. But that material is retained in proportion to the effort spent in learning it is axiomatic.

No one of these theories of forgetting is contradictory to the rest, and we shall see that there is experimental evidence for the truth of all of them.

THE CURVE OF RETENTION THE RATE OF FORGETTING

A QUANTITATIVE study of retention yields a continuous function representing the amount of material retained for each successive period of time elapsing after learning is completed. This function can be plotted in the form of a curve, on a graph whose abscissa represents units of time elapsed, and whose ordinate represents corresponding units of material retained.

Now, in the discussion of measures of retention, it was pointed out that a simple estimate of the number of items recalled is seldom an adequate measure of the retention of memory material. For example, a score of zero items recalled would not prove that nothing had been retained. This score must be supplemented by other tests, such as the relearning time, the saving score, or a recognition or reconstruction test. The saving score is the ratio of number of repetitions to relearn the material to number of repetitions necessary to learn in the first place.

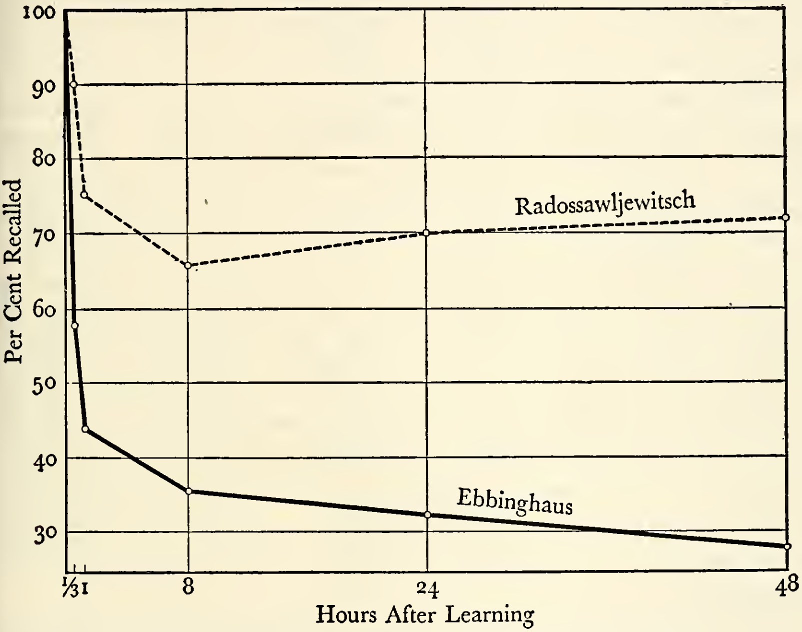


FIG. 72. Forgetting curves of Ebbinghaus and Radossawljewitsch compared

And if it is the retention of any act of skill that is being tested, the same ordinate units are used as those employed in measuring learning progress, i.e., units of output per unit of time, or units of time necessary per unit of output, giving a rate score; and errors per unit of time giving an accuracy score. The abscissa, of course, designates the units of time elapsed since learning ceased.

General Shape of Curve. — The first curve of forgetting was published by Ebbinghaus. He worked it out on himself as subject, using nonsense syllables for memorial material, and measuring retention by the saving method. Part of the curve is shown in Figure 72.

It is evident that the curve falls very rapidly at first so that over 40 per cent of the material is lost during the first half hour. Thereafter the drop is more gradual so that the general curve is negatively accelerated. Later work has established this as the typical forgetting curve, for memory material which has been learned to completion, except that the drop has been found to be less steep.

Numerous theories have been advanced to explain the negative acceleration of the forgetting function. A plausible one is that the items which were learned least well in the first place drop out first and leave the more thoroughly learned items whose tenacity is much greater. Another theory is based on the similarity of the shape of the forgetting function to the logarithmic curve. For example, it is argued by Chappell in a recent article that the forgetting function is only one of a large group of physical phenomena, all of which follow a logarithmic form because they obey the physical law governing the rate of dissipation of stored energy. Examples are the rate of dissipation of a head of steam from a boiler, or the loss of charge from a condenser. He compares learning to the storing of energy and forgetting to its dissipation.

Others have pointed to the likeness between the forgetting curve and the curve obtained in the action of a catalytic agent and argue that forgetting involves catalysis. These theories are at best analogies which, however, may prove fruitful points of departure in a physiological attack on the problem.

The Steepness of the Slope.—While investigators agree as to the general contour of the forgetting curve, they disagree about the steepness of the slope, particularly in the early stages. A comparison of the results of four investigators will bring out these discrepancies. The accompanying table gives the data of Ebbinghaus, Radossawljewitsch, Finkenbinder, and Luh, respectively. The figures represent percentages of the total list retained. The material is in all cases lists of 12 nonsense syllables and the relearning method was used in measuring retention. It will be noted that there are two columns headed "Radossawljewitsch." The first represents his results for 8, 12, and 16 syllable lists averaged. The second is for 12 syllable lists alone.

CURVE OF RETENTION FOR NONSENSE SYLLABLES

Interval	Ebbinghaus	Radossawljewitsch		Finkenbinder	Luh
5 min.		97.5	95.9		
20 min.	58.2	88.6	89.8		75
30 min.				75.0	
1 hour	44.2	70.7	75.3	72.8	65.9
2 hours				69.4	
4 hours				64.4	54.9
8 hours	35.8	47.4	66.3	65.5	
12 hours				63.8	52.1
16 hours				63.0	
24 hours	33.7	68.9	70.2	57.8	52.1
36 hours				58.8	
2 days	27.8	60.9	72.3	55.6	47.7
3 days				52.1	
6 days	25.4	49.3	59.5		
14 days		41.0	51.4		
21 days		37.8	48.6		
30 days	21.1	20.2	27.0		
120 days		2.8	3.3		

In interpreting the above results it is well to keep certain differences of method in mind.

Ebbinghaus used only one subject, himself, and learned only until one successful recall. We should expect forgetting to be more rapid, and a somewhat individualistic type of curve.

Radossawljewitsch used 29 subjects, and had them learn until two successful reproductions. Unfortunately he ignored diurnal variations of efficiency, and failed to eliminate the practice variable.

Finkenbinder used 14 subjects. Each was given five tests, making 70 values in all. Like Ebbinghaus, he required only one successful repetition as a criterion of learning. Unlike Radossawljewitsch, he eliminated practice effect and avoided diurnal efficiency variations.

Luh obtained 33 values each from 9 subjects. His criterion of learning was one successful trial.

The curves differ decidedly in general steepness and in the rate of negative acceleration. Ebbinghaus' curve is steepest in the early stages, but levels off so rapidly that by the 30th day it crosses that of Radossawljewitsch. The latter is the only curve to show reverses of trend. At 8 hours the per cent retained is 47.4, whereas at 24 hours it is 68.9, and does not again reach the low 8 hour level until the sixth day. Very possibly the effect is related to the intervention of sleep or the time of day at which the tests were made. Radossawljewitsch carried his curve to the 120th day, and thereby demonstrated that forgetting goes right on through this period, though at a reduced speed, until less than 3% is left.

REFERENCES

Chappell, M. N. Chance and the curve of forgetting. *Psychol. Rev.*, 1931, 38, 60–64.

Ebbinghaus, H. Memory, a contribution to experimental psychology. (Transl. by H. A. Ruger and C. E. Bussenius.) N. Y.: Teach. Coll. 1913.

Finkenbinder, E. O. The curve of forgetting. *Amer. J. Psychol.*, 1913, 24, 8–32.

Hollingworth, H. L. General principles of redintegration. *J. Gen. Psychol.*, 1928, 1, 79–91.

Lashley, K. S. Brain mechanisms and intelligence. Univ. of Chicago Press, Chicago, 1929, pp. 76–85.

Luh, C. W. The conditions of retention. *Psychol. Rev. Monog. Suppl.*, 1922, 31, No. 3, pp. 1–87.

Müller, G. E., and Pilzeker, A. Zeitschrift fur Psychologie, Erganzungsband I, 1900.

Radossawljewitsch, R. F. Das Fortschreiten des Vergessens mit der Zeit. Inaugural Dissertation. Univ. Zürich, 1907. Or, Das Behalten und Vergessen bei Kindern und Erwachsenen. Leipzig, 1907.

Titchener, E. B. Relearning after forty-six years. *Amer. J. Psychol.*, 1923, 34, 468–469.

CHAPTER XV

FACTORS INFLUENCING THE RATE OF FORGETTING

NOW that we have established the general shape of the forgetting curve, the question arises: To what extent is this typical form departed from, and what are the chief factors which influence the function? As the result of a careful series of experiments it is possible to state the influence of a large number of specific factors, among which are the age and intelligence of the subjects used, the nature of the material learned, the degree of learning, the method of measuring retention, and, most important of all, the activities engaged in during the retention period.

AGE

ONE of the most striking exceptions to the typical negatively accelerated curve of retention was reported in 1913 by Ballard under the title " Obliviscence and Reminiscence." He performed a series of experiments on children of different ages, from 6 to 21, in the learning of ballad poems. In the first study, which was performed on 5,192 school children, the ballad of " The Ancient Mariner " was learned. To this were later added studies on " The Wreck of the Hesperus," and nonsense verses. Fifteen minutes were allowed for the learning of 34 lines from " The Ancient Mariner." The subjects were then given an immediate recall test. They were then divided into groups, and given a second recall test at varying intervals after the first test, from 1 to 7 days. Figure 73 shows the average percentage recalled at each of these intervals. The ordinate expresses percent recalled, by considering the amount recalled immediately at 100%. The abscissa represents the intervals of time.

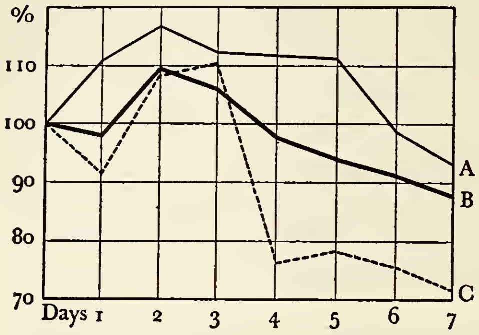


Fig. 73. Memory curves of 12-year-old children.

A. Wreck of the Hesperus. *B.* Ancient Mariner. *C.* Nonsense Syllables
From Ballard in British J. Psychol. Monog., 1913, 1, No. 2.

Obviously the striking thing about each of these average retention curves is that it rises during the first two days to a higher point than the immediate recall level. Thereafter the drop begins and continues at a slow rate. This phenomenon was called "Reminiscence," by Ballard. Several possible reasons suggest themselves at once. Learning of poetry differs from nonsense syllable learning. One has the advantage of rhyme and rhythm in recalling it. The subjects might practice on it during the interval. However, this was prevented by not warning them that a second test would be given, and taking children from widely separate schools.

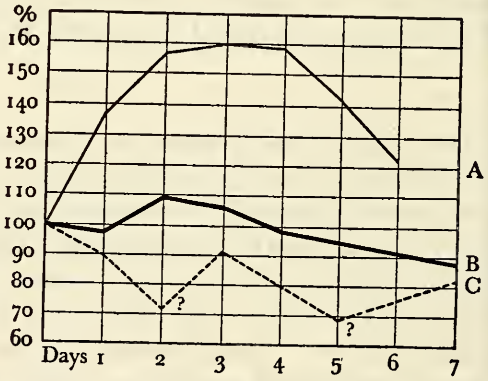


Fig. 74. Relation between age and reminiscence.

A. 6-year-old children. *B.* 12-year-olds. *C.* 21-year-olds
From Ballard in British J. Psychol. Monog., 1913, 1, No. 2.

There is still the possibility that poetry is unique material. The curves in the graph show differences in level for the three different materials used.

Again, there is the fact that only *partial learning* took place, whereas the Ebbinghaus curve was based on complete learning, and could not possibly show reminiscence. Most important of all, the subjects were children of 12 years of age, a unique fact in retention studies. Therefore Ballard systematically tested children of varying ages from 6 to 21. Appropriate materials, from "Wynken, Blynken and Nod" on up, were used. Figure 74 shows the comparative retention curves for three widely separate age groups. It is evident at once that the youngest age group has the greatest amount of reminiscence and that there is no reminiscence in the 20 year old curve, though reversals in trend do appear. This at once corroborates the previous hypothesis that reminiscence is a phenomenon characteristic of the memory of children, not of adults.

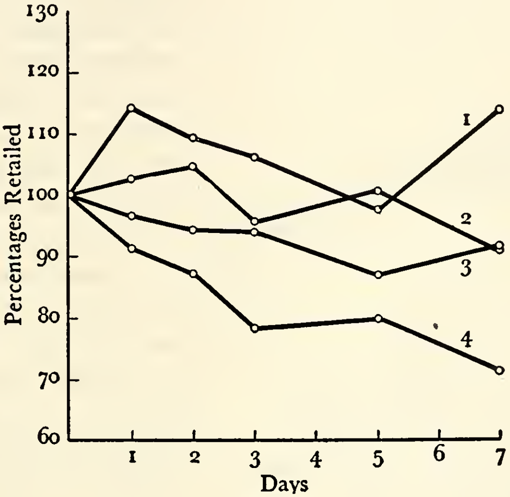


FIG. 75. Retention for poetry, correct verbal reproduction.

Curves 1, 2, 3, and 4 are for ages 9, 12, 16, and 21, respectively
From Williams in J. Exper. Psychol., 1926, 9, p. 373, Fig. 1.

If this were an isolated study the phenomenon might well be questioned; but a complete corroboration is available in the recent experiment of Williams. He investigated reminiscence in two types of material: (1) a meaningful connected passage of 40 lines of poetry, and (2) disconnected material in the form of a list of 50 abstract monosyllabic words. The

4,209 subjects were divided into 4 groups, according to age, group 1 averaging 9.6 years, group 2, 12.7 years, group 3, 16.2 years, and group 4, adults. Each age group was subdivided into 5 groups, each of which was tested for retention after a different interval, either 1, 2, 3, 5, or 7 days. They were always given five minutes to learn, with an immediate recall. Figure 75 shows the results for poetry, and Figure 76, those for disconnected material.

It is clear that the retention curve for the nine year old group rises approximately 15% during the first day and does not drop again to the initial level till after the third day. The retention curve for the 12 year olds also rises slightly, reaching a maximum after 2 days. But the 16 year old and adult curves show no reminiscence. *Age,* then, is an important factor.

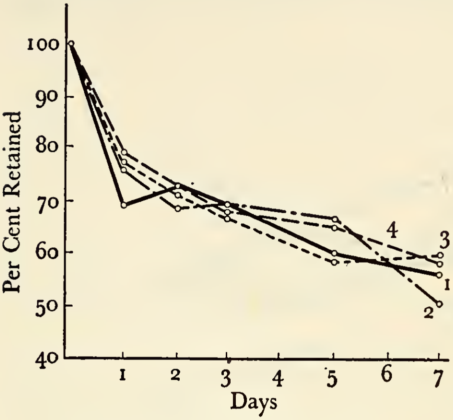


Fig. 76. Retention for disconnected material

From Williams in J. Exper. Psychol., 1926, 9, p. 374, Fig. 2.

Figure 76, which gives the retention curves for all age groups for disconnected material, shows no reminiscence at all. In fact all four curves display the typical Ebbinghaus form. It is evident from this that poetry, or at least meaningful connected passages, must be used. *Kind* of material is thus shown to be an important factor.

We may now sum up the factors that have been found to condition the appearance of reminiscence:

1. Age.
2. Kind of material.
3. Partial learning.

It is interesting to note that Henderson, in a study of the retention of partially learned prose passages by adults and children of different ages, obtained the greatest absolute amount of reproduction of ideas from the adults, for all periods, i.e., immediate 2 days and 4 weeks. But when the *relative* retention, i.e., percentage of the total amount learned, was computed, it was found that the children had the superior scores for the two-day interval. Both children and adults retained about the same number of words absolutely but *relatively* the children retained most for all intervals.

NATURE OF ORGANISM

Another striking exception to the Ebbinghaus negatively accelerated forgetting function is brought out in a comparison of the retention curves for maze habits of rats and humans. Tsai obtained negatively accelerated curves for human subjects on a stylus maze for all criteria, time, trials, and errors, although the rate of loss was very much slower than that for ideational learning as can be seen by a comparison of his data and those of Radossawljewitsch. Tsai's records on percentage of saving for the stylus maze habit were: 81 after seven days, 76 after fourteen days, 66 after twenty-one days, and 60 after thirty-five days. Radossawljewitsch, on the contrary, obtained saving scores in trials for nonsense syllables of 60 after six days, 51 after fourteen days, 49 after twenty-one days, and 27 after thirty days.

But, for both the maze habit and the problem box habit, Tsai obtained *linear* curves from rats. This held true by all criteria of learning and for all methods of measurement. The rate of forgetting is relatively slow, since only about 35% has been lost at the end of eight weeks. The difference between the human and animal curves might be partially explained by two considerations: (1) The learning trials were differently distributed. The rats were given one trial per day, whereas the humans learned the maze all at one sitting; (2) No doubt, the human subjects employed ideational processes to a much greater extent, even in learning a motor problem, than the animals. If it were possible to secure a retention curve for humans in which no ideational learning was involved, it might prove to be linear, though this is doubtful.

NATURE OF MATERIAL

THIS question has been partially answered in the two preceding sections. Ballard and Williams showed that the forgetting curve for poetry is unique, at least in the case of children. And Tsai showed that the forgetting curve for motor habits is much more gradual than that for ideational material. This phenomenon of relatively slow forgetting for acts of skill has long been recognized, and has been corroborated by a long line of investigators. In some cases an actual reminiscence has occurred, substantiating the dictum of William James that we learn to skate in summer and to swim in winter. For example, Book reports a growth in retention of the typewriting habit after rest. Thus, on the last regular practice period, Jan. 7, 1906, the average score in correct strokes on ten tests was 1,475 and the average per cent error 2.21. The first subsequent test was given on June 1, 1906, and the average stroke score was 1,391, with a 3.54% error record. The second test, given just a year later, showed 1,560 average correct strokes and 3.15% error. This gives an average gain in correct strokes for the second test of 85. Book himself attributes the effect, not to reminiscence but to " the disappearance with the lapse of time of numerous psycho-physical difficulties, interfering associations, bad habits of attention, incidentally acquired in the course of learning, which, as they fade, leave the more firmly established typewriting associations free to act." This, however, does not explain the loss between the end of practice and the first test, as compared with the gain from first to second test.

McGeoch has questioned the validity of the theory that motor habits are better retained than ideational ones. He attributes the difference in the curves to the fact that the motor habits receive a tremendously greater amount of overlearning at the time of acquisition. To test this he compared the retention scores on three stylus mazes of different difficulty with those on three different length lists of nonsense syllables, where the learning criterion was one perfect performance in both cases.

Each of the 24 subjects relearned both mazes and nonsense syllables one week after learning. Time, errors, and trials were used as criteria and savings scores were computed. The results give a greater saving in trials for the nonsense syllables, a greater recall for the mazes, and no consistent superiority for either type of task when time and error saving scores are used.

Within the field of ideational learning, or memory proper, are there any wide differences in retentivity for different materials? Apparently the significant split occurs between lists of disconnected items, such as digits, nonsense syllables, and even words on the one hand, and connected passages of prose or poetry, or the ideas contained therein, on the other. Notable studies are those of Bigham, Henderson, and Lyon. For example, Lyon had 20 college students learn completely one series each of 20 digits, 12 syllables, 20 words, 100 words of prose, and 100 words of poetry. At the end of three weeks the results on recall and relearning were, in percents:

	DIGITS	SYLLABLES	WORDS	PROSE	POETRY
Recall	18	21	36.5	58	68
Relearning	55	51.5	72.5	76	77

The words, prose, and poetry are much better retained than the digits and syllables; and both prose and poetry are significantly higher than words.

The variable factor is manifestly the degree of meaningfulness of the material.

One type of memory situation which yields very slow forgetting curves is the Aussage test in which the individual observes an event or a picture just once for a brief time and then recalls it later, either by the deposition or narrative methods of report. According to the former method the subject replies to set questions; according to the latter he tells what he can remember. Dallenbach used the picture method on 15 adults and 5 children, allowing 1 minute exposure and testing recall by both deposition and narrative, immediately and after 5 days, 15 days, and 45 days. His results do not give a true retention curve because of cumulative practice benefiting the values for the longer intervals. But if we compute percentage of material learned which was correctly recalled, calling the immediate recall 100%, we obtain the following values:

TIME INTERVALS		IMMEDIATE	5 DAYS	15 DAYS	45 DAYS
Adult	Narration	100	92	89.7	64.5
	Deposition	100	92.5	90.0	82.2
Juvenile	Narration	100	88.8	75.1	67.3
	Deposition	100	87.9	84.4	79.7

Obviously these values yield an extremely slow forgetting curve. What the results would be if each subject recalled only once, so as to eliminate the cumulative practice effect, we cannot say.

DEGREE OF LEARNING

A PRELIMINARY discovery by Luh, that overlearning is not uniformly advantageous, especially when carried beyond a certain point, raises the problem of the quantitative relation between retention and degree of integration beyond that which is just necessary for 100% correct immediate recall.

Luh used series of 12 nonsense syllables and tested retention at various intervals after learning. Four different degrees of learning were tried: 33%, 66%, 100%, and 150%. That is, if 12 trials were necessary for 100% correct anticipation, then 4 trials constituted 33% learning, and 8 trials constituted 66% learning. Retention was tested by reproduction, reconstruction, and recognition. His results for the reproduction criterion were as follows:

	PER CENT RECALLED *after*		
Degree Learning	4 *Hours*	1 *Day*	2 *Days*
150%	81.9	38.5	30.8
100	64.8	45.6	40.2
66	65.8	41.5	24.8
33	42.7	26.2	13.7

The striking thing is that 150% learning, or 50% overlearning, is advantageous for the 4 hour interval, but is slightly detrimental for the 1 day and 2 day intervals, as compared with 100% learning.

Krueger has recently checked on Luh's finding, in two experiments, one with lists of monosyllabic words, and the other with stylus mazes. In the first experiment he varied amount of learning from 100% to 200%, and used retention intervals of 1, 2, 4, 7, 14, and 28 days, testing retention by recall and saving. He found that, with learning up to 150%, or 50% overlearning, the increase in retention was roughly proportional to the extra effort. But beyond this, the law of diminishing returns operates. However, he never obtained the result that Luh got — that is, a detrimental effect of excess learning — even for the longer intervals of time. In fact, the longer the interval of time, the more likely was the extra learning to be beneficial, at least for 150% learning.

In the second experiment, with mazes, 100%, 150%, 200%, and 300% learning were tried. In all cases the saving scores were raised by the overlearning; but not proportionally to the amount of effort, especially beyond 100% overlearning. No consistent variation was found between increase in retention and length of interval.

We are compelled to conclude either that Luh's results, showing a detrimental effect of overlearning for longer intervals, are peculiar to nonsense syllables or that they are an artifact of the experiment. But what of the other finding, that the law of diminishing returns applies to overlearning? Ebbinghaus suggested that this might be the case, although he got no evidence for it in an early study of his, using 16 syllable nonsense lists.

Number of Repetitions	*Seconds to Relearn after 24 hours*	*Saving in Seconds*	*Saving over Added Repetition*
0	1270	—	—
8	1167	103	12.9
16	1078	192	12.0
24	975	295	12.3
32	863	407	12.7
42	697	573	13.6
53	585	685	12.9
64	454	816	12.8

Each added repetition has approximately equal effect.

Amount of Material and Retention

A corollary to the fact that retention is proportional to the degree of learning is the fact that longer lists are better retained than short ones. This follows from the greater number of repetitions necessary to fixate them. For example, Ebbinghaus found the following relation to pertain between number of syllables in list and per cent retained:

No. of syllables in list	12	24	36
Per cent retained	33	49	58

And Henmon obtained the following average results for six untrained subjects, learning nonsense syllables:

No. of syllables in list	10	12	14	16
Per cent retained	13.4	18.2	18.8	24.0

MEASURE OF RETENTION

Not all methods of recall or reinstatement yield equal retention scores. Some methods may be said to be more efficient or sensitive than others because they show a greater proportion of retention. For example, if a subject is asked to pick out items from a random list which he recognizes as having seen before, his score will invariably be higher than it would if he were asked to recall the items. This has been demonstrated by a number of investigators, notably Achilles. But what are the relative positions of written recall versus saving, or relearning, etc. The experiment of Luh gives a quantitative answer to the question. Luh compared five different methods of recall for nonsense syllables: (1) anticipation, or verbal recall, (2) relearning, (3) written reproduction, (4) reconstruction, and (5) recognition. He tested the percentage retained after 20 minutes, 1 hour, 4 hours, and 2 days. Figure 77 gives percentage retained against time interval. Each method of recall yields a separate curve.

An examination of the individual curves shows four of them consistently maintaining the following relative positions: recognition best, reconstruction next, written reproduction third, and anticipation poorest. The relearning curve, however, changes its relative position with time, so that, starting in fourth place, it eventually reaches second place, by cutting across the other curves.

While this study is not exhaustive it offers the most inclusive analysis of the problem obtainable.

INTERVENING ACTIVITY RETROACTIVE INHIBITION

THE problem of retention is the problem of maintaining intact over a period of time the impressions which were fixated in learning. Therefore it is essential to determine the influence on retention of the activities engaged in during the period of time between learning and recall. These interpolated activities, since they would require the functioning of the nervous system, would necessarily exert some effect, presumably disruptive, upon the neural patterns already established. In fact the only condition which would theoretically be free from such disruptive factors would be a state of dreamless sleep.

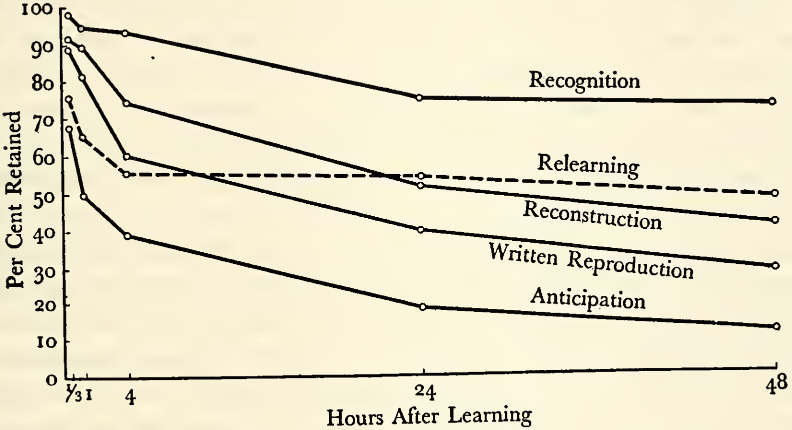


FIG. 77. Forgetting curves for different measures of retention

From Luh in Psychol. Monog., 1922, 31, No. 3, p. 31, Fig. 3.

The term most commonly applied to such a process of associative interference is "retroactive inhibition." This term, however, was first applied to the phenomenon by G. E. Müller and others, whose theoretical explanation of it was somewhat different from that now accepted. Their theory rested upon the assumption that learning is followed by a "setting-in" process, or "perseveration," which consists of the continued automatic excitation of the neural elements involved in the learning, for a short time after practice has ceased. Now, since this setting-in process was supposed to be essential to proper fixation, any interpolated activity introduced at this time was thought to inhibit or interfere with perseveration and thereby cause forgetting. The name, "retroactive inhibition" was therefore applied. As a result of these early assumptions, the history of experimentation in this field has been largely a series of attempts to break down or substantiate the fundamental postulates of the theory.

Müller and Pilzecker, the pioneer investigators, worked with nonsense syllables. Between learning and recall they interpolated three different conditions: either *rest,* or the memorizing of a *second list of syllables,* or memorizing *pictures.* Retention was tested by recall and relearning. They found an equal amount of retroactive inhibition, resulting from both kinds of interpolated activity as compared with rest; and therefore concluded that similarity of materials is not essential to the phenomenon but that *any strenuous* activity of the neural elements is sufficient. Moreover, in the case of one subject, whose interpolated activities were introduced six seconds after the original learning instead of the average of 17.2 seconds used with the others, the amount of retroactive inhibition was thereby increased. The conclusion was drawn that the perseverative process is most active immediately after learning and gradually reaches quiescence, so that the sooner the interpolated activity is engaged in the more harmful to retention it is.

These assumptions have therefore been judged crucial to the acceptance of the theory and hence experimental work aimed at the theory has attacked the following special problems:

The relation between the similarity of the interpolated task to the original learning and the degree of retroaction.

The relation between the temporal order of introducing the interpolated task (i.e., nearness to original learning) and the degree of retroaction.

The relation between degree of integration of the original material and its susceptibility to retroaction. A related problem, because of its bearing on the degree of integration, is that of the length of the original material.

Sleep as an intervening condition between learning and recall.

The significance of the last three problems will become clear if we consider what alternative theories have been advanced to replace the perseveration theory. The most widely accepted, the theory of *associative interference,* assumes that in the fixation of the interpolated material some of the associative bonds established in the original learning are cut across, and new cross associations are established. These cross associations then operate at the time of attempted recall and inhibit the original bonds from operating. Obviously if this were true there should be a direct relation between similarity and degree of retroaction, and the temporal order of the interpolated material would make little or no difference. Moreover, the degree of integration of the original material would be important, because cross associations would be less likely to interfere if the original bonds were strong. A similar argument would apply to the factor of length of original list, since Robinson demonstrated that longer lists are better integrated than shorter ones, since they receive a greater degree of overlearning. The significance of sleep as an interpolated condition lies in the fact that it satisfies the ideal of absolute inactivity during retention and hence offers an even greater opportunity for the so-called perseverative process to take place than waking rest.

Similarity and Retroaction

Following Müller and Pilzecker, Heine performed similar experiments on nonsense syllables testing retention by recognition, by recall, and by saving. For interpolated activities, she used learning of pictures, of lists of four place numbers, and of consonants. The recognition scores were unaffected by the interpolated activity, but the recall and savings scores showed inhibition as compared to a rest interval. All tasks interfered, but no opportunity is given for correlating degree of interference with degree of similarity of task.

DeCamp, using multiplication for interpolated work, found very little retroactive inhibition as compared with a rest interval. Comparing his results with Heine's he concluded that the discrepancy was due to the dissimilarity of his interpolated task to the learning, and suggested that the effects vary directly as the similarity.

In the animal field a comparison of the studies of Webb and Brockbank on rats is interesting. Webb used maze learning for both the original and interpolated task, a condition of high similarity, and obtained some retroactive interference. Brockbank used mazes for original learning and practice on a rope ladder problem for interpolated work. These problems are highly dissimilar. He not only failed to obtain interference, but got instead an actual facilitation of retention.

The first really systematic study of the similarity problem is that of Robinson. Three experiments were conducted. In the first and second, the original learning consisted of series of eight four place numbers. Fifteen seconds afterward the interpolated material was introduced. In Experiment I, this was one of five activities: (a) memorizing a second series of four place numbers, (b) memorizing consonants, (c) learning poetry, (d) solving multiplication problems, (e) just reading simple narrative prose. This last was equivalent to a rest period which insured standard conditions. The interpolated activity was always limited to just three minutes. Retention was tested by written reproduction in proper order, and the amount of recall, errors in position, and time of recall, were all computed. The average results on 15 subjects were:

Condition	*Amount Recalled*	*Errors*	*Time*
Numbers	15.4 digits	27.5%	5.73 seconds
Poetry	21.9 digits	19.3%	3.57 seconds
Consonants	22.4 digits	17.4%	3.07 seconds
Multiplication	22.1 digits	15.7%	3.55 seconds
Reading	22.8 digits	16.5%	3.03 seconds

The results show considerable disintegration of the lists, where original learning and interpolated task are highly similar, and the least effect where they are very dissimilar, as in reading.

In Experiment II, the interpolated work was either (a) learning four place numbers, (b) memorizing a series of 32 digits, (c) mental multiplication, (d) observing pictures of nudes, or (e) reading the newspaper. The results corroborate those of Experiment I very closely, demonstrating a direct relation between degree of interference and similarity of interpolated task.

Robinson's third experiment resembled one of DeCamp's in which the original learning consisted of memorizing a particular arrangement of chess men on a chess board. DeCamp had used arithmetical problems for interpolation and got no evidence of retroaction. Robinson used, for interpolated task, (a) another arrangement of chess men, (b) mental multiplication, and (c) reading. Retention was measured by accuracy of reconstruction of the chess pattern. Again, the highly similar interpolated work caused the greatest disintegration and reading the least.

These results throw considerable doubt on the conclusions of Müller and Pilzecker.

This experiment of Robinson's leaves the question still unanswered as to whether there is a degree of similarity so near identity that it would tend to facilitate rather than disrupt the original material. Certainly, if the interpolated list is absolutely identical with the original, any effort spent on it would help retention. The question is, at what stage in degrees of similarity does the transformation occur from increasingly greater interference to increasingly less. This can be determined only by using the same *sort* of material in original and interpolated learning, and systematically varying the number of identical elements in the two lists from a condition in which all elements are identical to one in which none are. The hypothetical law, the truth of which must be experimentally verified, is thus stated by Robinson: "As similarity between interpolation and original memorization is reduced from near identity, retention falls away to a minimum and then rises again, but with decreasing similarity, it never reaches the level obtaining with maximum similarity." He postulates the following graphical relationships between degrees of similarity and resulting efficiency of recall (see Figure 78). The extremes A and C represent absolute identity and absolute dissimilarity respectively. The same hypothesis has been expressed by Skaggs, but he considers the facts best represented bv two functions, one expressing the gradual falling off in facilitation from A to B, and the other expressing the gradual rise in inhibition from A to B, and the later falling off of this inhibition to a minimum at C.

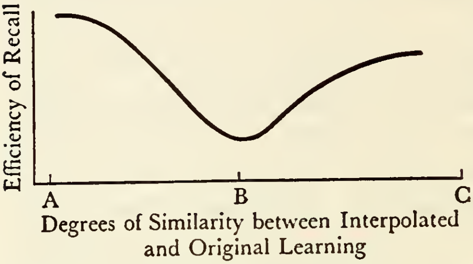


Fig. 78. Relation between similarity and retroactive inhibition

From Robinson in Amer. J. Psychol., 1927, 39, p. 299, Fig. 1.

Several experiments bear on the problem. Robinson used the memory-span type of experiment with immediate recall. An original list of four consonants was followed by an interpolated list of four consonants. Five conditions of similarity were used: no items in common, one in common, two in common, three in common, and four in common. The lists were presented visually in one study and auditorially in a second. The average results are presented graphically, in Figure 79. There is evidence for a gradual falling off in efficiency of recall with increasing dissimilarity of lists; but within the limits employed no inversion occurs although an asymptote is obviously reached at the last stage. Robinson concludes that the hypothetical curve with its inversion is not universally true. But obviously he has not given the theory a fair trial, since even zero identity of items still involves a high degree of similarity of tasks, since both lists contain consonants. Two other studies have appeared, one of Harden, and one of Cheng.

Harden systematically altered the kind of material between original and interpolated list by using consonants in the former and digits in the latter. Thus the series BLFP–7469 represents zero similarity and BLFP–XCJD represents maximum similarity because all of the items are consonants. Harden obtained, as a result of her method, a curve corresponding to the theoretical function, i.e., first a decrease in amount recalled, with decreasing similarity and then a sudden sharp increase as zero similarity is reached. Cheng used lists of nonsense syllables for original and interpolated material containing one, two, or three letters in common. Measured in terms of recall, retroaction at first increases and then decreases as degree of similarity increases from zero to two identical letters. This tends to substantiate the theoretical curve.

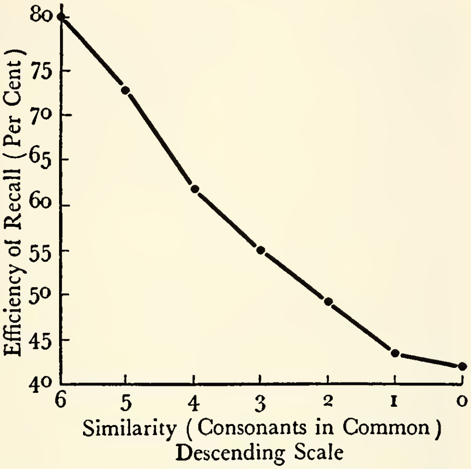


Fig. 79. Relation between number of identical elements in the original and interpolated list and the efficiency of recall

From Robinson in Amer. J. Psychol., 1927, 39, p. 311, Fig. 7.

While the results are not unequivocal it seems safe to conclude that the theoretical law expressing the relation between similarity and retroaction is, in general, true.

Temporal Position and Retroaction

But what of the factor of temporal position? Is it true that the interpolated activity is more disruptive when introduced immediately after the original learning than at any later time? Robinson investigated this problem also. Using lists of 10 three-place numbers for the original task, he tried five different conditions of interpolation introduced twenty seconds later: (a) twenty minutes reading the newspaper; (b) five minutes learning three-place numbers and fifteen minutes reading; (c) five minutes reading, five minutes learning numbers, ten minutes reading; (d) ten minutes reading, five minutes learning numbers, then five minutes reading; (e) fifteen minutes reading, then five minutes learning numbers. Thus the interpolated activity occurred at four different intervals after learning. The resulting effects on retention are as follows:

Condition	*Amount Recalled*	*Errors*	*Time*
A	29.1 digits	6.1%	1.6 seconds
B	18.6 digits	31.9%	5.9 seconds
C	19.7 digits	29.0%	5.5 seconds
D	19.2 digits	32.6%	6.4 seconds
E	18.4 digits	30.3%	6.9 seconds

Evidently it makes very little difference what the interval of time is. This result is fatal to the perseverative theory unless it is assumed to go on with practically undiminished strength for a long time after learning instead of being the temporary affair that Müller assumed. Fortunately, more recent experiments give us evidence on this also, though they are not in agreement with one another. Whitely studied the influence of an apperceptive set aroused by congruous interpolated material on recall. He found not only that the interpolated material exerted a detrimental influence whether it was introduced prior to recall or immediately after learning; but it was least detrimental after learning. The time elapsing between learning and recall was either 24 or 48 hours, so that any hypothetical perseverative process should have ceased long before the time of recall. Skaggs, on the other hand, found that interpolated activity introduced immediately after learning is more detrimental than when a rest period intervenes. The author himself has, however, found in a series of experiments with nonsense syllables, in which the interpolated list was placed, (a) immediately after learning, (b) immediately before recall (one hour later), or (c) half way between (i.e. after a half hour); that condition " (b) " is worse than " (a)," but both " (a) " and " (b) " are worse than " (c)." This may account for Skaggs' finding.

The weight of evidence seems to be against the "perseveration" hypothesis.

Degree of Integration and Retroaction

If retroactive inhibition is assumed to be a disruptive action upon previously established bonds in the nervous system, then there should be a definite relation between the strength of those bonds and their susceptibility to disintegration. Whatever contributes to the strengthening of the original bonds should increase their resistance. Several phases of this problem have been experimentally attacked. They are (a) the influence of degree of learning, (b) the influence of amount of material learned, and (c) the influence of the conditions under which learning takes place, whether favorable or unfavorable.

Degree of Learning. — The first investigator was Heine. She performed seven experiments with nonsense syllables in two of which saving was used as a test of retention; and in the other five recall was the criterion. Two degrees of learning were employed and she compared the amount of inhibition present with these two degrees. The reliability is questionable since only one subject was used in each experiment, but her results show greater inhibition with fewer learning trials.

The next experiment, that of Robinson, was designed to expand Heine's findings by multiplying the number of degrees of learning used. Lists of 10 three-place numbers were exposed 4, 6, 8, 10, or 12 times with 20 seconds elapsing between successive exposures of the list. An interval of 5½ minutes occurred between learning and recall during which the subject rested, read the newspaper in the control condition and studied a second list of 10 three-place numbers for 8 trials for the experimental condition. The criteria of recall were amount, error, and time. The results are shown in the following table. They were obtained by dividing the difference in efficiency between control and experimental conditions by the efficiency under the control condition.

	RELATIVE INHIBITION			
Presentations	*Amount*	*Time*	*% Error*	*Gross Error*
4	59.3	233	26	−51
6	56.6	151	73	−25
8	45.4	115	98	+8
10	45.3	176	156	+41
12	47.3	367	117	+14

The general tendency is in the direction of a decrease in inhibition with an increase in number of presentations in accordance with the amount criterion, but by the error criterion there is an increase in retroaction with an increase in number of presentations.

In a later study made by McGeoch, 9 syllable lists were learned by the anticipation method to 6, 11, 16, and 21 repetitions, and the interval between learning and recall was filled either by a rest or the learning of 9 syllable lists to 11 repetitions. For the greater number of presentations there was a high degree of overlearning of the original lists. As measured by recall, relearning and saving scores, retention increased in proportion to the number of repetitions, and the relative amount of retroactive inhibition varied inversely as the number of presentations in learning.

Amount of Material Learned. — It has already been suggested that retention is better for longer lists than for shorter lists, although there seems to be a lower limit to this law. We can explain the fact by assuming that longer lists receive a greater amount of overlearning than shorter lists because, although in terms of presentations, there is a saving in number of learning trials necessary with increasing length of list, yet there is an increase in the relative amount of time necessary. Consequently, arguing on the basis of the greater overlearning of longer lists, we might assume that such lists would be more resistant to retroactive effects on the basis of the studies just described. As a matter of fact this has been found to be true in an experiment by Robinson and Heron, using nonsense syllables, and by Robinson and Darrow using digits. Tests were made of the influence of length of list upon susceptibility to retroactive inhibition. There is a definite tendency toward decreasing susceptibility to disintegration with increasing length of list, with a possible lower limit to the law just as in the case of length in relation to retention.

Conditions of Learning.—Tolman measured the susceptibility of materials to retroaction when learned under the following conditions: (1) pleasantly- vs. indifferently-toned materials; (2) normal vs. distracted attention; (3) with and without caffein; (4) at efficient vs. inefficient working periods. In every case but one, the more favorable conditions were accompanied by a smaller amount of retroactive inhibition, but in the case of the distracted attention the disintegration was least. The results are hardly very reliable but they are to be expected in view of the discovery of Morgan and others that distraction is accompanied by an increased mental effort.

Lester compared the amount of retroaction under different learning sets, (a) where the subject is warned to learn so as to avoid the retroactive effect, and (b) where he merely knows about the effect but makes no effort to overcome it, with a control condition in which he knows nothing about it. She found that the effects of retroaction could be greatly reduced by the subject's set.

Sleep as Compared with Waking Rest

All previous studies of the retroaction phenomenon have assumed tacitly that a condition of rest, or reading light literature, constitutes the minimum degree of interpolated activity and, hence, forms a control condition against which to compare the other interpolated activities. However, it is logical to assume that even a condition of waking rest involves some use of the central nervous system. This can be determined by comparing retention over a period of waking rest with retention over a period of sleep. Three studies have attacked this problem. Jenkins and Dallenbach used intervals of sleep of 1, 2, 4 and 8 hours, as compared to similar intervals of waking rest. They find that more than twice as many syllables are reproduced by their subjects after intervals of sleep, and this, however, increases in proportion to the length of the interval. Dahl repeated their experiment using recognition as a criterion of retention. Sleep proved the better condition when failure to recognize constituted the criterion, but when false recognitions were counted, sleep was superior only for the longer intervals. This is interpreted by him to imply that it is the condition of the subject at the time of recall rather than the intervening activity which determines the efficiency of retention. There seems very little basis for this interpretation, especially in view of the experiment of Spight. Her purpose was to compare the rest value of day and night intervals between learning periods; i.e., her subjects learned lists of 14 paired associate words to the point where they were able to recall half the items. They then rested 12 hours and continued the learning to completion. Since half the subjects took their first learning period at night and the other half reversed this procedure, the matter of efficiency of the time of learning is pretty well ruled out. She found the mean trials required for total learning with daytime rest to be 5.52; whereas that for night rest was 4.93. The difference is small but significant.

It is possible that the findings of these investigators throw light upon the discrepancy in the Ebbinghaus forgetting curve, which shows a slower rate of forgetting from 8 hours to one day than from one day to two days, and the curve of Radossawljewitsch with its enormous deviation at the close of the eighth hour. At least Finkenbinder, who was careful to distribute learning times throughout the day, got no such deviation.

Effect of Learning Ability and Intelligence

To what extent is good retentive capacity correlated with the learning ability and the general intelligence of the subject? Learning ability has been found to be positively correlated with retention in general, but the results are complicated by several factors. To begin with, there is a fallacy in correlating absolute speed in learning with absolute amount retained, because the rapid learners would learn a greater amount of material and hence would be expected to recall more, regardless of their retentive capacity. It is necessary to equate the amount learned, using time as a criterion of learning ability, or else to compute percentage scores showing amount retained *relative* to amount learned.

The relation of learning ability to retention might also be expected to vary with the type of material. For example, one would expect a difference between meaningful and rote types of material.

There is also reason to suspect a difference with different measures of retention. For example, Luh has pointed out that by the method of computing the savings score there will necessarily be a negative correlation between learning speed and saving. Other measures of retention should, however, yield positive correlation if any relation obtains between the two abilities.

Unfortunately, the experiments are nearly all complicated by one or another of these factors.

Norsworthy tested 83 students on several series of 10 German-English paired associates. They studied them 20 minutes per day for 5 days. They were tested immediately for number learned at the end of each study period. Every subject learned at least 200 pairs. One day following the last practice period they were given a recall test of 50 words and another at the end of a month. The correlation between amount learned and the first test was .41; that between amount learned and the second test was .50. The greater retention of the fast learners could not be due to the greater amount learned because all were tested on the 200 words which they knew. In fact, the fast learners spent less time on the 200 words on which the test was based than the slow learners. The correlation coefficient agrees fairly closely with Thorndike's uncorrected coefficient of .55 between number of words learned in a single auditory presentation and number recalled in a written reproduction test given one day later.

Differences due to type of material are brought out by Henderson. He gives correlations on 12 subjects between amount of material learned (from 3 prose passages) in three minutes, and amount retained after two days and four weeks. The correlation between absolute amount of ideas learned and retained after two days and after 4 weeks is 1.00; whereas the correlation between relative amount of ideas learned and retained after the same periods is .70. Contrasted with this, the correlation between absolute amount of *words* learned and retained is .60 after two days, .70 after four days; whereas the correlations between relative amount of words learned and retained after these periods are —.10 and +.10, respectively. The difference between the logical memory involved in the retention of ideas and the rote type of memory involved in the retention of words is thus clearly brought out.

Lyon also investigated the problem of differences of material, using digits, syllables, isolated words, words of prose, and words of poetry. Both written recall and relearning were used to measure retention. By the recall criterion, he found a negative correlation between learning and retentive ability in the case of digits, while syllables, words, prose and poetry gave positive correlations. By the relearning criterion the quickest learners are the poorest retainers. But as has been pointed out by Luh, this is an artifact resulting from the peculiarities of the relearning criterion, which would be expected to yield negative correlations.

The other problem, that of intelligence as related to retention, has been studied only recently. Lee correlated intelligence with scores on four memory tests. Retention was tested after 30 seconds and after 24 hours by both recall and recognition. All correlations were positive, but the amount of relationship varies with both material and method of measurement. The coefficients stand in decreasing order, thus: pictures of familiar objects, words, syllables, and geometrical forms. McGeoch compared two groups of equal chronological age, one normal, the other subnormal, in ability to observe and report on the Binet object card and the picture and event forms of the Aussage. The normal group showed a smaller percentage of error and a larger range of items attested. An exception to the general rule is the phenomenal memory of certain individuals of low grade intelligence whose feats of memory have been reported. The only possible explanation is that they spend an inordinate amount of time committing the useless information which they collect and that they employ special mnemonic systems which they have hit upon by chance.

Recall or Rehearsal During Retention

Numerous experimenters have discovered that a second recall is likely to be better than the first. It was partly this phenomenon which led Ballard to advance the hypothesis of reminiscence. He discovered that if subjects were asked to recall ballads learned a long while beforehand they invariably got better scores on the second day's attempt than on the first day's. Warner Brown asked 194 students to write in 5 minutes the names of as many states as they could. A half hour later they were asked without warning to repeat the test. The results were as follows:

Number recalled, first test	36.31
Number recalled, second test	39.66
New items appearing in second test	5.29

The same group learned a list of 48 unconnected words to two presentations. The results for an immediate test, and one after a half hour, were:

Number recalled, first test	25.48
Number recalled, second test	26.77
New words appearing in second test	4.33

Garry Myers obtained even larger differences in the recall of almost-forgotten selections from literature. The following results are based on six cases:

	1	2	3	4	5	6
% recalled, 1st test	20.4	33.3	55.5	18.8	60	16.6
% added in later recalls	44.9	44.4	33.3	81.2	35	35.5
Total % of selection recalled	65.3	77.7	88.8	100.0	95	52.1

ORGANIC STATUS DURING RETENTION

Whatever neural or general physiological conditions exist during the retention period influence the efficiency of retention. Any emotional or physical trauma may produce either an anterograde or a retrograde amnesia (i.e., forgetfulness for impressions received previous to, or subsequent to, the trauma). A recent laboratory experiment verifying this is the study of Harden, on emotional interference. A condition of three minutes' rest between the learning and recall of nonsense syllable lists was compared with a condition of emotional excitement produced by various stimuli, among which were, in addition to some discarded in a preliminary study, sudden loss of bodily support, firing a gun, brilliant flash of lights, and electric shock applied through wristlets. Three main experiments were run and the trends discovered were consistent throughout, even though the averages in each case were not statistically significant. The forgetting, as measured by number of items correctly recalled, was always slightly greater with the shock condition. In one case, complete amnesia occurred. Also, the time of recall was greater, and especially was this true of the first syllable recalled after the shock. In Experiment 2, 26 subjects required, on the average, twice as long to recall this first syllable as after rest; and in Experiment 3, 46 subjects required three times as long.

Stone introduced various emotional stimuli immediately after the learning of lists of nonsense syllables. Among these were gazing at pictures of famine victims, reading about Indian tortures, etc. The most effective was the dropping of a match into a basket of waste paper so that the basket burst into flame, apparently accidentally. Large effects on the scores resulted, but they were not consistent either in a facilitative or inhibitive direction. For example, in the case of S 2, the change was from 12.5 to 3; whereas with S 4 it was from 4.5 to 9. In six cases it was positive, and in 4 negative. Blood pressure records were taken before and after the giving of the emotional stimulus, and these also were higher in some cases and lower in others. But the experiments employing horror stimuli usually gave depressed blood pressure records, and consistently produced inhibitive effects on recall.

The ambiguous results in the case of the conflagration stimulus suggest that amnesia is not an invariable result of emotional shock, but that hypermnesia may sometimes follow. Stratton has brought together a large number of anecdotal cases in which subjects report hypermnesia caused by traumas. These hypermnesias were sometimes temporary, sometimes permanent. They might be retrograde or anterograde. They might be general or selective, picking out specific details. And in some cases there would be a mingling of hypermnesia and amnesia. For the same person, the stretch of time preceding the critical event may show an irregular alternation of heights and depressions, vivid recollections followed by a period of utter blank.

Other influences which might enter into the retention period and exert either a beneficial or detrimental effect, are disease, nutritional factors, insomnia, drugs, and artificial dissociations as produced by hypnosis.

Illustrative of the last type of influence are the findings of Strickler in his quantitative study of post-hypnotic amnesia. Four subjects, who were found to show complete waking amnesia for events occurring in hypnotic trances, were experimented upon as follows: — Lists of nine paired associates consisting of simple geometric characters with their arbitrary nonsense names were learned by the prompting method to perfect repetition. Retention was tested by recall and relearning. In a control condition, both learning and recall were performed in the waking state, fifteen minutes apart. In the experimental condition, the learning occurred in the trance, and the recall occurred 15 minutes later in the waking state. Under both conditions a second relearning occurred after 24 hours. The results show a recall amnesia for material learned in the trance of about 98%, or about 80% when the amount of forgetting which occurred in the control condition is subtracted. The amnesia as measured by relearning score is about 50%. This is in spite of the fact that learning in the trance took about 36% more trials than in the waking state. These results suggest that the dissociation of memorial bonds which is effected in passing from a hypnotic trance to a waking state is extremely profound. On the other hand, if recall is definitely suggested during the trance, as in the case of posthypnotic suggestions, the associations thus formed will operate for weeks or months afterward. This has been verified by Patten and others.

Finally, the effects of extirpation have already been mentioned. Lashley finds that the amnesia for the maze habit in the white rat, as measured by the trials necessary to relearn the habit, is roughly proportional to the extent of the lesion.

This applies to cortical lesions only. Lashley and McCarthy failed to produce any disturbance whatsoever in the retention of maze habits by severe injuries to the rats' cerebellum.

REFERENCES

Achilles, E. M. Experimental studies in recall and recognition. *Arch. Psychol.*, 1920, 6, No. 44, pp. 80.

Ballard, P. B. Obliviscence and reminiscence. *Brit. J. Psychol. Monog. Suppl.*, 1913, 1, No. 2, 1–82.

Bigham, J., and Munsterberg, H. Memory. *Psychol. Rev.*, 1894, 1, 34–48.

Book, W. F. Psychology of skill, with special reference to its acquisition in typewriting. N. Y., 1925, Gregg Pub. Co.

Brockbank, T. W. Redintegration in the albino rat. A study in retention. *Behav. Monog. Suppl.*, 1919, 4, No. 2, pp. 1–66.

Brown, Warner. To what extent is memory measured by a single recall? *J. Exper. Psychol.*, 1923, 6, 377–382.

Cheng, N. Y. Retroactive effect and degree of similarity. *J. Exper. Psychol.*, 1929, 12, 444–449.

Dahl, A. Ueber den Einfluss des Schlafens auf das Wiedererkennen. *Psychol. Forsch.*, 1928, 11, 290–301.

Dallenbach, K. M. The relation of memory error to time interval. *Psychol. Rev.*, 1913, 20, 323–337.

De Camp, J. E. A study of retroactive inhibition. *Psychol. Monog.*, 1915, 19, No. 84, 1–69.

Ebbinghaus, H. Memory. Ruger translation. N. Y. Teach. College. 1913.

Finkenbinder, E. O. The curve of forgetting. *Amer. J. Psychol.*, 1913, 24, 8–32.

Harden, L. M. A quantitative study of the similarity factor in retroactive inhibition. *J. Gen. Psychol.*, 1929, 2, 421–432.

Harden, L. M. Effect of emotional reactions upon retention. *J. Gen. Psychol.*, 1930, 3, 197–221.

Heine, R. Ueber Wiedererkennen und rückwirkende Hemmung. *Zsch. F. Psychol.*, 1914, 68, 161–236.

Henderson, E. N. A study of memory for connected trains of thought. *Psychol. Rev. Monog., Suppl.*, 1903, 5, No. 6, 1–94.

Henmon, V. A. C. The relation between learning and retention and amount to be learned. *J. Exper. Psychol.*, 1917, 2, 476–484.

Jenkins, J. G., and Dallenbach, K. M. Obliviscence during sleep and waking. *Amer. J. Psychol.*, 1924, 35, 605–612.

Krueger, W. C. F. The effect of overlearning on retention. *J. Exper. Psychol.*, 1929, 12, 71–78.

Krueger, W. C. F. Further studies in overlearning. *J. Exper. Psychol.*, 1930, 13, 152–163.

Lashley, K. S. Brain mechanisms and intelligence. Univ. of Chicago Press. 1929, pp. 76–85.

Lashley and McCarthy, D. A. The survival of the maze habit after cerebellar injuries. *J. Comp. Psychol.*, 1926, 6, 423–433.

Lee, A. L. An experimental study of retention and its relation to intelligence. *Psychol. Monog.*, 1925, 34, No. 157, pp. 45.

Lester, O. P. Mental set in relation to retroactive inhibition. *J. Exper. Psychol.*, 1932, 15, No. 6, 681–699.

Luh, C. W. The conditions of retention. *Psychol. Monog.*, 1922, 31, No. 3, pp. 87.

Lyon, D. O. Memory and the learning process. Baltimore, 1917. Warwick & York.

McGeoch, J. A. The fidelity of report of normal and subnormal children. *Amer. J. Psychol.*, 1925, 36, 434–445.

McGeoch, J. A. The influence of degree of learning upon retroactive inhibition. *Amer. J. Psychol.*, 1929, 41, 252–262.

McGeoch, J. A., and Melton, A. W. The comparative retention values of maze habits and of nonsense syllables. *J. Exper. Psychol.*, 1929, 12, 392–414.

Morgan, J. J. B. The overcoming of distractions and other resistances. *Arch. Psychol.*, 1916, 5, No. 35, pp. 84.

Müller, G. E., & Pilzeker, A. Experimentelle Beiträge zur Lehre vom Gedächtniss. *Zeitsch. f. Psychol.*, Erg 1, 1900, 1–300.

Myers, G. C. Recall in relation to retention. *J. Ed. Psychol.*, 5, 119–130.

Norsworthy, N. Acquisition as related to retention. *J. Ed. Psychol.*, 1912, 3, 214–218.

Patten, E. F. The duration of posthypnotic suggestion. *J. Abn. and Soc. Psychol.*, 1930, 25, 310–334.

Radossawljewitsch, R. F. Das Behalten und Vergessen bei Kindern und Erwachsenen. Leipzig, 1907.

Robinson, E. S. Some factors determining the degree of retroactive inhibition. *Psychol. Monog.*, 1920, 28, No. 6, pp. 36.

Robinson, E. S. The similarity factor in retroaction. *Amer. J. Psychol.*, 1927, 39, 297–312.

Robinson, E. S., and Darrow, C. W. Effect of length of list upon memory for numbers. *Amer. J. Psychol.*, 1924, 35, 234–243.

Robinson, E. S., and Heron, W. T. Results of variations in length of memorized material. *J. Exper. Psychol.*, 1922, 5, 428–448.

Skaggs, E. B. Further studies in retroactive inhibition. *Psychol. Monog.*, 1925, 34, No. 161, pp. 1–60.

Skaggs, E. B. The major forms of inhibition in man. Univ. Chicago Press, Chicago, 1931.

Spight, J. Day and night intervals and the distribution of practice. *Jour. Exper. Psychol.*, 1928, 11, 397–8.

Stone, A. R. The reaction of memory to affective states. *Amer. J. Psychol.*, 1925, 36, p. 113.

Stratton, G. M. Retroactive hypermnesia and other emotional effects on memory. *Psychol. Rev.*, 1919, 26, p. 474.

Strickler, C. B. A quantitative study of post-hypnotic amnesia. *J. Abn. & Soc. Psychol.*, 1929, 24, 109–119.

Thorndike, E. L. The relation between memory for words and memory for numbers and the relation between memory over short and memory over long intervals. *Amer. J. Psychol.*, 1910, 21, 487.

Tolman, E. C. Retroactive inhibition as affected by conditions of learning. *Psychol. Monog.*, 1918, 25, No. 1, pp. 50.

Tsai, C. A comparative study of retention curves for motor habits. *Comp. Psychol. Monog.*, 1924, 2, 29.

Webb, L. W. Transfer of training and retroaction. *Psychol. Rev. Monog. Suppl.*, 1917, 24, No. 104, pp. 1–90.

Whitely, P. L. The dependence of learning and recall upon prior intellectual activities. *J. Exper. Psychol.*, 1927, 10, 489–608.

Williams, O. A study of the phenomenon of reminiscence. *J. Exper. Psychol.*, 1926, 9, 368–387.

CHAPTER XVI

RECALL AND RECOGNITION

THE THIRD distinct process involved in memory is that of reinstatement or recall. Recall is dependent on both learning and retention, but is not guaranteed by them. If it were true, as often suggested, that no impression is ever completely lost from the nervous system, we should nevertheless still have the problem of recall as a distinct one.

FORMS OF RECALL

In its broadest sense, recall or reinstatement includes all the possible ways in which impressions function in thinking and acting. This would include imagining, reasoning, free association, and practically all behavior. But in actual usage we are interested primarily in the formal reinstatement of definite things. Of these, there are three more or less distinct kinds:

(1) Reinstatement of a learned act or habit, using the identical movements originally employed. This is the manner in which acts of skill are recalled. It may or may not be accompanied by symbolic processes. For example, a person who learned to swim last summer may *remember* how to swim this summer. This implies that he can actually perform the movements of swimming. But it may also imply that he can tell how to swim properly. This involves more than just reinstatement of the act, and belongs under our second category.

(2) Reinstatement of symbolic substitutes, either for movements, or for perceptual objects or ideas experienced at a previous time. This is " memory " proper.

Under this would be classed recall of lists of words, or pictures or ideas from one's reading or objects or scenes one has viewed. Since this involves using a symbolic thought substitute for the actual thing it is called ideational recall and the symbolic processes are designated memorial ideas. Such ideas may take various forms at different times or with different persons. They may be *images,* as when we recall the actual visual appearance of a friend, or the sound of his voice. Or they may consist of sensory content which we use symbolically to stand for the thing remembered, as in the case of diagrammatic sketches. Or they may be symbolic movements, verbal, gestural, postural, having a representative function, as when a shudder serves the function of reinstating an emotional attitude. Finally, there is the possibility that we sometimes recall in terms of "contentless" processes, which have been called *"imageless thoughts."* Something of their sort seems to be present in cases of recognition, where we have a feeling of familiarity which cannot be tied down to any feature or concrete memorial process. This differs from the preceding sufficiently to be placed in a third class, namely:

(3) Recognition, or the arousal of meaning with no specific carrier. This process has been studied independently of the others by special techniques which will be described later. It proves to be the most efficient kind of reinstatement, in the sense that it gives evidence of memorial traces when the other kinds fail to show any residue.

THEORIES OF RECALL

In describing the theories of forgetting we seemed to imply that it was necessary to explain the *failures* of recall, but that *successful* recall is self-explanatory. Such is not the case. We must account for recall.

Association.—The most widely accepted theory uses the concept of laws of association. First formulated by Aristotle, these laws have been variously revised and formulated since. A possible version of the laws is one which divides them into the primary laws and the secondary laws. The former are contiguity, similarity, and contrast. The latter are frequency, recency, intensity, vividness, and emotional congruity. The secondary laws are so called because they state the conditions under which the primary laws operate. Critics of these laws point out that they merely classify the phenomena under logical categories rather than getting at their psychological basis. It is claimed that the laws are *descriptive* rather than *explanatory* and hence not fundamental. It is not essential that laws be stated in physiological terms, but it is essential that they state the *necessary* conditions for the appearance of the phenomenon. Evidently, there is duplication in the association laws as stated. Carr has reduced them to two: contiguity and assimilation. The latter refers to that condition of association, whatever it is, on which judgments of similarity between terms are based.

The other psychological explanations which have been advanced are perseveration and intuition. "Perseveration" assumes a persistence of the neural excitation involved in learning. It is invoked to explain the running of a tune in the head, the persistence of a particular thought which seems to forcibly thrust itself upon us, and similar spontaneous revivals. The "intuition" theory is little more than a recognition of the problem and adds nothing to its understanding. The Gestalt concept of "Einsicht" as a sudden integration taking place without conscious associative antecedents is apparently concerned with the same type of phenomenon. The lively current interest in Gestalt interpretations shows that the problem is a vital one. Intuition is supposed to operate independently of reflective thinking and to explain spontaneous appearance of ideas. Neither of these, i.e., intuition or perseveration, can be afforded scientific status at present.

On the neural side, recall is supposed to result from the easy arousal of neighboring patterns between which and the stimulated pattern the resistance has been lowered by learning. In so far as doubt has been cast on the synapse hypothesis, some other concept, such as fields of attraction, can be substituted without altering the broader interpretation of the concept.

FACTORS INFLUENCING THE EFFICIENCY OF RECALL

RECALL efficiency can be measured in several different ways. We may be interested in the speed of recall or the time elapsing between the giving of the stimulus to recall and the occurrence of the response. This criterion is used in studies of free association and sometimes in the conventional memory studies, but it presents difficulties in technique. Time may be kept with a stop watch, but for accurate timing it is necessary to use a voice key or lip key in connection with a chronoscope. The more usual method is to limit the time allowed for recall to a constant amount, such as 3 seconds, or 5 seconds, and if recall does not take place in this time, an error is registered.

A second criterion is completeness of recall; i.e., the number of items recalled. Usually this is complicated by the fact that certain items may be partially recalled, or may be recalled in the wrong order, and therefore a third criterion commonly used is accuracy of recall. The experimenter may insist on absolute accuracy of form and position, or position may be disregarded and correct form insisted upon, or credit may be given for items which are partially correct. For example, in the case of the nonsense syllables, a graded number of credits may be given for one letter, or three letters correctly reproduced. A fourth criterion of efficiency depends upon whether the material is recalled in such a form that it is related to the needs of the individual at the time.

In general, the factors influencing recall may be divided into those relating to the conditions pertaining at the time of learning, those factors operating during retention, and those factors present at the time of recall. The first of these classes of factors has been discussed under the topic of learning, but we will here designate briefly the nature and degree of their influence on recall.

Influence of Conditions at the Time of Learning

Method of Learning.—The subject's ability to recall material is a function of the degree of attention and effortfulness with which the material was originally learned. For example, if the subject is informed at the time of learning that he will be expected to recall at a given time, his recall will be more efficient than if he were ignorant of this. If he is warned at the time of learning that recall will take place under peculiarly distracting conditions, he can learn in such a way as to minimize or reduce the influence of these conditions. It is even possible for a subject to reduce the amount of retroactive inhibitive effect of interpolated material introduced between learning and recall, provided he is warned of the phenomenon and urged to avoid its effects. Studies illustrating these points are the following: Geyer compared the recall efficiency of subjects under two conditions; one condition in which they were informed that they would be tested immediately or after 24 hours, and the other condition in which they were tested at a different time from the time at which they were told to expect the test. In all cases the change in time was detrimental.

Burri studied the effect of presence of an audience at the time of recall. A list of nonsense syllables was learned and recalled under two conditions; one with an audience, and one without. Not only did the audience prove inhibitive in the majority of cases, but the subjects learned differently when anticipating an audience. More trials were used in learning in this case. Lester compared the effects of retroactive inhibition under several conditions; where interpolated material was introduced without the subject being forewarned, where the subject was warned that it would be introduced but was not informed of its effect, and where he was warned of its coming and informed of the effect and urged to exert an effort to avoid the effect. She found a much greater amount of retroaction in the first two cases. This result can be interpreted in various ways, but an examination of the learning records shows that the subjects learned with an entirely different attitude when they were preparing to resist the influence of subsequent retroactive effects.

Effortfulness can be given a physical interpretation in terms of increased tension of the musculature during learning. That material learned under conditions of increased muscular tension is recalled with greater facility was demonstrated by Bills. The following table shows the relative efficiency of recall under the conditions of normal and increased muscular tension.

NUMBER OF SYLLABLES RECALLED (ten lists averaged)

Subject	*Tension*	*Normal*	*Per cent Gain from Tension*
A	5.2	5.1	2.0
B	5.7	5.2	9.6
C	4.1	2.9	41.4
D	4.0	1.9	111.0
E	2.5	3.6	— 30.5
F	0.5	2.8	— 82.0
G	6.5	5.5	18.2
H	5.6	4.7	19.2
I	5.3	3.9	36.0
Av.	4.4	3.9	13.0

Distribution of Effort. — The assumption that the most efficient method of learning will necessarily yield the best recall score, particularly after longer intervals, is not always justified. Rapid learning is not necessarily thorough learning. The truth of this is brought out in comparing the retentive values of concentrated and distributed practice. It is demonstrated, for example, in Robinson's study, in which the learning of a list of 10 three-place numbers was either concentrated into one sitting of 6 readings, or divided into 2 sittings of 3 readings each. The concentrated study proved more efficient as tested by recall 5 minutes after the last reading. But by 20 minutes afterward this superiority of the concentrated form of study had been lost; and by 24 hours afterward the distributed study was clearly better. The consensus of opinion favors distributed practice for the greater efficiency of recall after larger intervals. Austin found that five concentrated readings of logical material were as good as one per day, for five days, when tested by immediate recall; but with recall after two weeks, the divided practice was three times as effective.

As to distribution of rest intervals, Tsai finds the most efficient recall of paired associates when learning trials are distributed in such a way that short rest intervals occur at first and increasingly longer ones later. This is in accordance with the assumption of a negatively accelerated curve of forgetting.

Methods of Presentation.—It is unfortunate that most of the results on sense avenue, on organization of learning material, etc., neglect to show the delayed recall effects of the various methods. The results might be reversed. For example, Kirk tested the relative value of the visual-auditory-vocal method and the visual-auditory-vocal-graphic method of teaching feeble-minded boys to recognize written words. Time per presentation was equated for the two groups. In the second method the boys traced the words with a stylus in addition to pronouncing them. Whereas learning time was practically equal for the two methods, recall as measured by the saving score was superior for the graphic method with all subjects.

Condition of Subject.—The status of the subject at the time of learning has a marked effect on the subsequent recall of material. Tolman demonstrated that lists learned under more stimulating conditions, i.e., with caffeine, when the subject was rested, and when the words were pleasant, yielded better recall scores than lists learned under less stimulating conditions. Morgan found fatigue an important factor. His subjects spent 4 hours studying the English equivalents of 850 German words, and after 2 days were tested for recognition, recall, and relearning. The recognition scores for material in the five successive divisions of the learning period were 5.47, 4.34, 3.66, 3.16, and 2.79 respectively. The recall scores were 0.40, 0.23, 0.17, 0.22, and 0.21. The relearning scores as percentages of the learning scores were 89, 81, 78, 74, 71. The material learned later, when fatigue had set in, was recalled less well by all three criteria.

Affective Tone and Emotional Factors.—The results of studies of affective tone and retention are extremely contradictory. A review of all the more important results has been made by Meltzer. Some of the contradictions are due to differences in procedure, but frequently are attributable to differences in the bias of the experimenter and hence in the interpretation placed on the data. The main question at issue is whether pleasant materials are, or are not, better remembered than unpleasant or indifferent materials. A subordinate question, raised by the Freudian hypothesis of repression, is whether unpleasant materials are repressed.

Among those whose results are consistently negative are Gordon and Wolgemuth. In an early study in which 7 trained subjects were tested for recognition of colored figures and protocols after 3 weeks, Gordon found no difference between the records for unpleasant, pleasant, and indifferent material. Recently she conducted two other experiments on large numbers of subjects. In one, 200 students were tested on the recollection of 10 pleasant and unpleasant odors. They recalled 49% pleasant, 50% unpleasant, and 56% indifferent odors. A correlation of —.07 was obtained between affective value and memory values. In the other study 750 students described their earliest memories and analyzed them for their affective value. The male subjects recalled 25% pleasant and 53% unpleasant, while the females recalled 35% pleasant and 46% unpleasant, respectively. This last study is open to the objection which should be raised against all those studies employing the questionnaire procedure. We do not know whether the subjects had an equal number of pleasant, unpleasant, and indifferent experiences to begin with.

Wolgemuth avoided this pitfall in his investigation of the remembered experiences of 687 school children, aged 11–16 years. He had them recall their personal experiences once, then waited ten days and asked for a second recall. It is on the basis of the forgetting between the first and second recalls that he bases his conclusions. The average percent of pleasant experiences forgotten for each child was 38.2 against 35.3 unpleasant.

Wolgemuth is inclined to draw too sweeping negative conclusions from his data due to his violent bias against psychoanalytic doctrine as a whole, and against the doctrine of repression in general.

On the other hand, Washburn and her students, in a long series of studies, have obtained consistently positive results. For example, Washburn, Field, and Wolf, using ninety college girls as subjects, asked them to recall occasions on which they were angry, afraid, or joyful. In a later study from the Vassar laboratory, two new emotions, pride and shame, were added. Reaction time was taken, and the subjects rated the vividness of the revived experience on a scale of four degrees. Recency of the experience was taken into account. Joy was more often and more intensely revived than fear or anger. The values obtained were: joy, 168; fear, 108; anger, 104. Moreover, joy was recalled quickest. The average intensity and quickness of recall for pride, proved to be next in order to joy.

In later studies, Washburn and her students have used the free and controlled association techniques, accompanied by galvanometric measures. They have found that subjects classified as cheerful recall far more pleasant than unpleasant associations. Emotional and calm subjects recall joyful experiences about equally, but a larger proportion of the emotional subjects recall anger and fear incidents, than of the calm ones. Eighty per cent of the subjects who gave galvanometric deflection above the median amount during recall of incidents producing anger, joy, and fear were in the groups rated as emotional.

Griffitts also found pleasant materials retained best, but noted that as between unpleasant and indifferent words, the unpleasant yielded the best recall. His method differed from others in that he presented stimulus words of which an equal number were calculated to call up pleasant and unpleasant associations. It was thus the power of stimuli, in discrete free association, to call up effectively toned associations, that he was measuring. Later he had them recall as many of the stimuli as they could. The continuous free association method, in which the subjects were to write as many pleasant or unpleasant words as they could in a limited time, also yielded more pleasant words. The ratio of pleasant to unpleasant associations showed a correlation of .47 ± .06 with self-estimates of cheerfulness. Griffitts concludes that "an affective reaction of any kind is favorable to the recall of the stimulus."

A novel slant to the problem was contributed by Laird.

At the beginning of a class hour he asked 62 subjects to write down the names of ten acquaintances. At the end of the hour they were asked to rate the names of their acquaintances in order of their preference from most liked to least liked. The experimenter then compared these ratings with the original lists to find out whether it was the most liked or least liked acquaintances who appeared most often in these lists. For the group as a whole, the most liked persons appeared most often. But he had previously divided the subjects, on the basis of their own and others' judgments, into three groups, (1), the optimists; (2), the pessimists; and (3), the mixed group. On this basis, it was possible for him to discover that while the optimists recalled the names of their most liked acquaintances oftenest, the pessimists showed the reverse tendency.

Perhaps the greatest advance made by all these studies is in demonstrating that no simple one-to-one relation exists between affectivity and memorial value, but that any emotional tone attached to stimuli probably tends to enhance their recall value, and that the particular type is correlated with individual temperaments. The Freudian doctrine of repression has neither been finally established nor finally refuted.

Influence of Conditions at Time of Recall

The importance of the activities engaged in between learning and recall has already been discussed in connection with the topic of retention and need not be repeated here. Of equal importance for recall efficiency is the general setting at the time of reinstatement. Much depends upon the kind of recall that is asked for; whether it consists in an actual performance of a previously acquired habit, or an ideational revival. Then, again, the results differ depending on whether an anticipatory recall, a written or oral reproduction or reconstruction is asked for, or a mere recognition of items. We have seen that the last named form of recall invariably yields the largest values.

Kind of Recall.—An interesting analysis of the influence of the form of recall upon its efficiency is brought out in the experimental studies of testimony. The aussage test, which was introduced by the German psychologist Stern, is especially adapted to bringing out these differences. This test takes three forms: the picture test, in which the subject is presented with a picture showing an event, which is exposed for a short time, say one minute; the event test, in which an actual event is staged so that the subjects can see what takes place; and the rumor test in which information is conveyed through the spoken word. A recall test is then given either immediately or after a lapse of an interval, and it commonly takes one of two forms, the narrative or the deposition. The narrative test merely calls for as complete as possible a statement from the observer in his own words. In the case of the deposition, a series of specific questions is asked to which the observer must respond categorically. Both tests are rated in terms of their completeness and accuracy. Either type of statement may be given under oath or not. Sworn statements are more accurate, though less complete. From a large number of studies, sworn statements have been found to yield 11% errors, unsworn statements 20%.

The greatest sources of error lie in the deposition due to the nature of the questions that may be asked. Out of 240 reports, only 4 errorless narratives and but one errorless deposition were obtained. The average accuracy of reporters is about 75% correct information. Questions asked in depositions fall into four main classifications: determinative, disjunctive, expectative and implicative. For example, suppose the question at issue is whether or not a certain participant in an event had a hat on. The determinative type of question would be, "Did the individual wear a hat?" The disjunctive question would be worded, "Did, or did not, the individual wear a hat?" The expectative question would have the form, "The individual wore a hat, didn't he?" The implicative question would read, "What color was the individual's hat?" thus implying that the individual had a hat on, whether he did or not.

It can easily be seen that the implicative question is the most confusing, while the determinative is least so.

Another source of error in report is the emotional nature of the situation under which the original observation was made, and under which the report is given, especially in court testimony. Eye witnesses have been found to be considerably more accurate than hearsay witnesses. Their depositions are 58% correct as opposed to 34% for the hearsay witnesses. Repetition is a source of further error since repetition makes the observer more sure of himself and consequently more certain of the correctness of his wrong answers. Stern has catalogued errors of testimony under four headings: (1), errors of observation; (2), errors of memory; (3), errors of imagination; (4), errors of judgment. The more imaginative person and the person of less mature judgment is more subject to error. This invalidates the testimony of children and uneducated persons. Stern finds men somewhat more accurate than women.

Accuracy of report depends in part on the thing reported about. Statements about persons and their actions and objects are, on the average, 85% accurate, whereas statements about the qualities of objects and particularly quantitative statements regarding measures of time and distance, are only 45% accurate. A lengthening of the time interval between observation and report reduces the accuracy and range of the testimony, but in proportion to the rate of forgetting in the typical forgetting curve. Sometimes an actual improvement occurs. For example, Dallenbach, using the event method, obtained the following values:

EVENT METHOD

Time	*Questions Answered*	*Per cent Error*
0	880	14
5 days	855	18
45 days	801	23

Constancy of Conditions from Learning to Recall

In discussing the theories of forgetting, we mentioned prominently the lack of an adequate stimulus. It is a common observation that if one meets an acquaintance in a strange environment it is difficult to recall his name. Recall attains its highest efficiency when the general setting at the time of recall is identical with that existing at the time of learning. This statement is not to be interpreted as implying that no revival can occur without the repetition of the entire stimulus situation. Hollingworth's principle of redintegration calls attention to the fact that one element in a total stimulus situation may call out the response which was originally elicited by the total situation. In fact, in many cases in which meaning operates it does so through the ability of the part to suggest the whole; but the fact remains that any alteration of the stimulus situation tends to render the recall less complete. The importance of the principle warrants more experimental attention than it has received. Possibly it would be an elaboration of the obvious.

The pioneer work was done on animals. Watson, after training rats on a maze problem, rotated the maze in such a way as to alter the surrounding environment and then retested his animals. Both time and errors were increased, showing an interference with the functioning of the habit. Carr made a more systematic study of the problem. He altered the conditions at the time of recall in a number of ways; for example, covering or uncovering the maze, changing illumination, rotation or change of position of the maze in the room, and changing the experimenter's position. Not all changes were effective on all rats, but a change in the experimenter's position affected all the animals and caused an increase in error from 0.11 to 2.50 per trial.

Carr concluded that " Any sensory-motor act cannot be regarded as an isolated independent function; the act was learned within a wider sensory environment, and it never ceases to be wholly free from these conditions either during or after its development."

On human subjects, Smith and Guthrie describe a study in which the subjects learned and relearned lists of 10 nonsense syllables in the following ways:

1. Learned and relearned both in laboratory.
2. Learned in laboratory and relearned outdoors.
3. Learned outdoors and relearned in laboratory.
4. Learned and relearned outdoors.

They found that an average of 11.4% fewer repetitions was required to relearn in similar surroundings.

In another experiment, thirteen subjects had to learn to copy a list of letters on a specially arranged typewriter keyboard. An odor of oil of peppermint gave the characteristic environmental setting. Later the test was repeated. They report that the average saving in the time required to repeat the list was 9.4 percent greater when the repetition took place under the condition of the first practice.

An extremely illuminating study is that of Pan, already mentioned. He required subjects to memorize pairs of words presented with various contexts accompanying them, and 24 hours later they were tested for their ability to recall these lists when the context was present, absent, or altered in certain specified ways. Three kinds of context were used — words, numbers, and, in a subsidiary experiment, pictures. The words to be memorized were typed in capitals and the contextual words were typed in small letters immediately above and below the associated items. The context was either logically related or unrelated to the stimulus word or the response word. Recall took place with either (1) removal of the context that was present during learning; or (2), the introduction of a new context; or (3), interchanging of contexts for different items; or (4), no change in context. The results show that to remove a context logically related to the response word, or to stimulus and response both, is highly detrimental; but to introduce such a context in recall for the first time is beneficial. On the other hand, to remove a logically unrelated context is beneficial, and to introduce it into recall for the first time is slightly detrimental.

Floors conducted an experiment in which he had his subjects memorize geometrical figures of different sizes. These sizes were altered or held constant between the impression and the recall which occurred five minutes later. Three conditions were used: (A) Figures were the same size in impression and recall test. (B) Figures were constant in size during impression, but were changed in recall test. (C) Figures were varied in size during impression, and appeared in still another size in the recall test. The best results were obtained when the size was constant for both impression and test. The worst results occurred in condition B. This experiment corroborates a similar one of Lambrecht performed previously on color and form.

Besides changing the subject's extraneous environment it is possible to alter his own intraorganic condition in various ways, as to neural or glandular or postural state, thereby inhibiting recall. Reed studied postural changes and found that a radical change of posture between learning and recall of word lists interfered with the reinstatement process. She found also that a shift from visual to auditory presentation of stimuli, or vice versa, had an inhibitory effect. Burri found the presence of an audience detrimental, during recall of material which had been learned in solitude. There is some evidence, however, that this detrimental effect can be minimized provided the subject knows beforehand that a particular change is to be made.

One interesting way in which the factor of changed conditions shows itself is in the superiority of forward over backward recall. Presumably, the subject learns the pairs of items to be memorized in a paired associate list in such a way that the association will work in a forward direction; when the first item appears the second is recalled. Therefore, when the procedure is reversed, and the second item is presented as the stimulus, the first item fails to be recalled with anything like the same facility. Müller and Pilzeker obtained the following values: —

ORDER OF TEST	PER CENT RECALLED
Forward	50%
Backward	38%

Wohlgemuth found, however, that if the subject is given a backward set instead of a forward set at the time of learning, he can recall as readily in a backward as in a forward direction.

Subject's Attitude. — Finally, recall efficiency depends intimately upon the emotional and volitional attitude of the subject at the time of the recall test. Perfect learning and perfect retention are no guaranty of good recall. Psychoanalysis had made much of the principle of the censor, which is a figurative way of saying that strong emotional inhibitive attitudes or sets are present in the average individual which block the recall of material incongruous with these attitudes. The bare principle has considerable truth in it, without doubt. It is the elaborate accessory drapery of Freudian doctrine — the assumption of an unconscious storehouse of ideas in suspended animation — that seems superfluous to the orthodox psychologist. Emotional reinforcement and emotional inhibition as applied to recall are commonplace doctrines of orthodox psychology.

Some investigators into the borderline phenomena of abnormal psychology, such as hypnosis, report various special devices which seem to promote reminiscence, such as crystal gazing, automatic writing, and the trance state itself. All of these special devices seem to involve the shutting out of distracting stimuli, and the freeing of the associational processes, so that weaker associations are brought within the recall threshold. It is only in a figurative sense that we need to explain the results in terms of the tapping of unconscious storehouses.

RECOGNITION AND RECALL

One form of recall which is usually distinguished from it as a separate process is recognition. As has been pointed out, it is the most efficient of all forms of recall as measured by the criterion of the amount reinstated, because all that is required is for the subject to recognize that the item is one which has been presented in past experience, without any reconstruction of the details of the item itself. The material must merely have what is called the familiarity feeling.

The usual method of studying recognition is to present the subject with items which have been previously presented for learning, and ask him whether he recognizes them or, as in the method more usually applied, the familiar items are placed in a larger list of items many of which have never been presented before. The subject is asked to select the familiar items. Guessing is allowed because the boundary line between recognizing and not recognizing an item is often hazy.

Among the factors which affect recognition memory are:

(1) the amount of material presented; (2) the time interval; (3) the frequency and intensity of the stimulus, etc. Strong found that whereas after an interval of 15 seconds the subjects recognized 84.6% of the material, after a half hour this had dropped to 55.5%; after a day to 28.8%, and after 42 days to 6.3%. This shows a slighter negative acceleration than is present in the forgetting curves of Ebbinghaus. Luh also found a slower forgetting for the recognition type of memory. Studies of the value of advertisements of varying sizes and vividness show that the percent recognized increases with the size and the frequency of presentation of advertisements. An interesting discovery of Heine, in her experiments on retroactive inhibition, was that recognition memory is not affected by interpolated activities, showing that recognition memory depends upon the establishment of some sort of traces of associational bonds. However, when introspective studies have been made of processes of recognition, there seems to be a relation between the feeling of familiarity which arises and the actual appearance in consciousness of associations with the particular item whose total or partial arousal gives the feeling of familiarity to the item. It has been suggested that it is possible that the associational factors which are responsible for recognition are largely subthreshold, and hence non-specific — not recognized for what they are by the subject when he reacts to them.

REFERENCES

Austin, S. D. M. A study in logical memory. *Amer. J. Psychol.*, 1921, 32, 370–403.

Bills, A. G. The influence of muscular tension on the efficiency of mental work. *Amer. J. Psychol.*, 1927, 38, 227–251.

Burri, C. The influence of an audience upon recall. *J. Ed. Psychol.*, 1932, 22, 683–690.

Carr, H. A., and Watson, J. B. Orientation in the white rat. *J. Comp. Psychol. and Neurol.*, 1908, 18, 27–44.

Carr, H. A. Maze studies with the white rat. I. Normal animals. *J. Animal Behav.*, 1917, 7, 259–75.

Carr, H. A. The laws of association. *Psychol. Rev.*, 1931, 38, 212–228.

Dallenbach, K. M. The relation of memory error to time interval. *Psychol. Rev.*, 1913, 20, 323–337.

Floors, M. Ueber den Einfluss der Grossen varierung bei Gedächtnessleistungen. *Zeitsch. f. Psychol.*, 1922, 90, 307–28.

✓ Geyer, M. Influence of changing the expected time of recall. *J. Exper. Psychol.*, 1930, 13, 290–292.

Gordon, K. Ueber das Gedächtnis für Affectiv bestimmte Eindrücke. *Arch. f. d. ges. Psychol.*, 1905, 4, 437–458.

Gordon, K. Recollection of pleasant and unpleasant odors. *J. Exper. Psychol.*, 1925, 8, 225–239.

Griffitts, C. H. Results of some experiments on affection, distribution of associations, and recall. *J. Exper. Psychol.*, 1920, 3, 447–464.

Hollingworth, H. L. General principles of redintegration. *J. Gen. Psychol.*, 1928, 1, 79–91.

Janet, P. The major symptoms of hysteria. New York: Macmillan. 1920. P. 345.

Kirk, S. The influence of manual tracing on the learning of simple words in the case of subnormal boys. *J. Educ. Psychol.*, 1933, 24, 525–535.

Laird, D. A. The influence of likes and dislikes on memory as related to personality. *J. Exper. Psychol.*, 1923, 6, 294–303.

Lambrecht, K. Ueber den Einfluss der Verknüpfung von Farbe und Form bei Gedächtnisleistungen. *Zeitsch. f. Psychol.*, 1915, 71.

Lester, O. P. Mental set in relation to retroactive inhibition. *J. Exper. Psychol.*, 1932, 15, No. 6, 681–699.

Meltzer, H. The present status of experimental studies on the relationship of feeling to memory. *Psychol. Rev.*, 1930, 37, 124–139.

Morgan, J. J. B. The effect of fatigue on retention. *J. Exper. Psychol.*, 1920, 3, 319–333.

Müller, G. E., and Pilzeker, A. Experimentelle Beiträge zur Lehre vom Gedächtniss. *Zeitsch. f. Psychol.*, 1900, Ergbd. 1, 300.

Pan, S. The influence of context upon learning and recall. *J. Exper. Psychol.*, 1926, 9, 468–491.

Reed, H. J. The influence of a change of conditions upon the amount recalled. *J. Exper. Psychol.*, 1931, 14, 632–649.

Robinson, E. S. The relative efficiencies of distributed and concentrated study on memorizing. *J. Exper. Psychol.*, 1921, 4, 327–343.

Smith, S., and Guthrie, E. R. General psychology in terms of behavior. N. Y. 1921.

Stern, L. W. Abstracts of lectures on the psychology of testimony and on the study of individuality. *Amer. J. Psychol.*, 1910, 21, 270–282.

Tolman, E. C. Retroactive inhibition as affected by conditions of learning. *Psychol. Monog.*, 1918, 25, No. 1, pp. 50.

Tsai, L. S. The relation of retention to the distribution of relearning. *J. Exper. Psychol.*, 1927, 10, 30–39.

Washburn, M. F., Field, R., and Wolf, E. D. A study of revived emotions. *Amer. J. Psychol.*, 1923, 34, 99–103.

Washburn, M. F., and Pisek, F. Galvanometer experiments with revived emotions as a test of emotional and phlegmatic temperaments. *Amer. J. Psychol.*, 1925, 36, 459–461.

Watson, J. B. Kinaesthetic and organic sensations; their role in the reactions of the white rat to the maze. *Psychol. Monog.*, 1907, 8, No. 33.

Wohlgemuth, G. A. On memory and the direction of associations. *Brit. J. Psychol.*, 1913, 5, 447–465.

Wohlgemuth, G. A. The influence of feeling on memory. *Brit. J. Psychol.*, 1922–23, 13, 405–429.

Part Four—Association and Thought

CHAPTER XVII

ASSOCIATION AND DISSOCIATION

THE PROCESSES of learning and recall are implicit in all thinking, whether it be purposeful thinking or mere phantasy, and whether it deals with concrete situations or abstract conceptual matters. The question is, what are the ways in which learned habits actually function in the thought process when they are not mere formal responses to specific stimuli formally presented? To answer this question requires a consideration of the processes of free and controlled association, and of the processes of generalization, abstraction, and concept formation which are involved in problem solving on an ideational level, i.e., reasoning in the restricted sense.

Studies of association and dissociation are distinguished from studies of memory only in terms of experimental tradition. The work on memory and retention assumes the operation of the laws of association, but is chiefly interested in the operation of these laws at the time of recall. Association studies differ from recall studies in that there has been no previous record of the conditions under which the associations were originally formed. In short, it is an attempt to determine the way in which the laws of association operate in the free train of ideas involved in everyday thinking. It is assumed that by analyzing the responses, it is possible to classify the various types of association which produced these responses.

Historically, the interest in association goes back to Aristotle's formulation of the laws of contiguity, similarity, and contrast. The addition of the so-called secondary laws of recency, frequency, and vividness occurred about the beginning of the nineteenth century. Dissociation is a concept which has come to us from abnormal psychology and its study was given impetus by the theoretical system which Janet developed to explain the symptoms of hysteria and related nervous diseases.

The Concepts

The original formulation of the doctrine of association of ideas by the English Associationists limited its application to ideas. In the mental realm, it was supposed to be comparable to the concept of gravitation in physics as a universal principle of integration amongst ideas. The recent criticism of mentalistic psychologies has brought " associationism " into disrepute. There is no reason, however, why the general principle of association should be rejected, provided it is not applied exclusively to association of ideas, but is broadened to include all forms of integration, including the conditioning of reflexes and other stimulus-response organizations. The concept has changed from that of association of ideas to that of association of neural elements or of stimulus objects and as such is implicit in all learning.

The opposite concept, that of dissociation, which is implicit in the theories of forgetting, has, however, been chiefly emphasized by students of abnormal psychology. Two outstanding schools may be contrasted in terms of the explanations they offer for dissociation. On the one hand, the school of Janet assumes dissociation to result from a lowering of the level of tension within the central nervous system. Conditions such as neural fatigue, traumas of emotional or physical origin, fevers, sleep, and the like cause dissociations amongst neural patterns; i.e., failure of associational bonds to function. The other school assumes an active psychic dissociating process, called " repression " which detaches certain impressions from the integrated body of conscious experiences. This active inhibiting principle, the Censor, operates in accordance with the supposed law of avoidance of the unpleasant and of the socially unacceptable. To this school, dissociation is therefore always a result of emotional conflict. The dissociated material or process does not cease to influence behavior but gains expression in dreams, neurotic symptoms, and the like.

THE TYPES OF ASSOCIATION EXPERIMENT. FREE AND CONTROLLED

TRADITIONALLY there are two main kinds of association experiment: free association and controlled association. The names are confusing because neither is completely free nor completely controlled. They differ in degree. But their difference in purpose is clear enough. Free association aims to discover the unguided course of ideas when they merely follow the bonds established by random past experience. Controlled association, on the contrary, aims to discover how this course is changed by introducing a definite controlling *set* into the process.

Free association can be either *discrete* or *continuous*. According to the former method, a list of words is presented to the subject, visually or auditorily, one by one, and he is directed, usually, to respond with the *first* word which comes into his head after hearing the stimulus word. The response is limited to the extent that it must be a word, and the first word. Otherwise it is free. The method gets its name from the fact that each response is made to a discrete stimulus. According to the continuous method, on the other hand, the subject is started off by a single word, and responds with every word that suggests itself until he is told to stop. Aside from the original stimulus, and the definite time limit, there are no restrictions whatever.

The kinds of controlled association, on the other hand, are as varied as the sets that can be imparted to the subject. Among the more common are those requiring that the subject's responses bear one of the following relations to the stimulus: some logical relation, as part-whole, genus-species, opposites, superordination, subordination, and the like; response by analogy; and responses which are dictated by the nature of the problem, as in arithmetical computations, etc. The nature of the directions may be such as to produce all degrees of control over the responses.

RESULTS OF FREE ASSOCIATION EXPERIMENTS

Time Relations; Their Significance

One of the most important characteristics of responses in free association is their speed, i.e., the time elapsing after the stimulus is given. The standard apparatus for timing responses is the stop watch. Time may be taken for each discrete response in terms of fifths of a second, or a cumulative record may be kept and the average response then computed. When it is necessary to have more accurate time records, some mechanical timing device is used; for example, with verbal responses it is necessary to use a voice key or a lip key in circuit with an electrically controlled pen, recording kymographically. For discrete reactions, a voice key may be arranged to control a Dunlap or Hipp chronoscope which is accurate to a thousandth of a second.

The significance of time relations lies in the insight which they give into the readiness of the particular bond to operate. Such readiness can be a function of various things. It may indicate the strength of the original association or it may reveal an emotional block of some sort which is inhibiting the association from operating. An especially long time is usually interpreted as evidence of emotional conflict, particularly if it occurs in response to so-called critical stimuli. Usually there are other complex indicators in addition to the time factor, such as blushing, nervousness, stuttering, and the like.

The average time of free association responses is from 1 to 3 seconds, whereas delayed responses may take as much as 10 seconds. Free association times are, as a rule, longer than controlled association times, due to the greater vagueness of the controlling set; also to the operation of inhibitions. Individuals differ greatly in their speed. According to Wells, the reaction times of men range from a median of 1.5 seconds to 2.7 seconds, whereas those of women range from 1.4 to 4.4. There is a tendency for subjects to increase their speed with practice in free association, although practice also tends to make the responses more commonplace and of a more superficial type. Fatigue has this same effect.

An experiment of Blase demonstrates this fact very clearly. She gave the Kent-Rosanoff series to a group of subjects over and over again at a single sitting, until the subjects were thoroughly fatigued. She found that the nature of the associations tended to break down and become more like those of schizophrenic patients, with perseverative and rhymed responses increasing. On the other hand, the communality of the responses increased considerably.

Factors Influencing the Nature of Associations

In addition to the effects of practice and fatigue, characteristic differences have been found correlated with differences in intelligence, age, etc. Rosanoff compared the responses of 21 bright, 21 average, and 21 dull children. The percentages of common responses secured were 79, 75, and 67 respectively, showing a higher degree of communality for the bright group. Other authors, as Meumann, find a greater degree of originality in the responses of intelligent children. Meumann also notes a tendency of intelligent subjects to misinterpret the stimulus, to fail to respond, and to give irrelevant, superficial, and perseverative responses. These tendencies would reduce their communality scores fictitiously. In the case of adults of the average age and intellectual level of college students, individuality of response has been found to correlate positively with intelligence test scores. Feeble-minded children examined at Vineland by Miss Otis showed a tendency toward repetition of the stimulus, multiverbal responses and predicative responses, i.e., as wood — it burns. A retardation was noted in the appearance of normal responses.

Age is an important factor. Children give fewer common responses than adults. This individuality is partly a result of lack of attention to instructions resulting in repetition, perseveration, and non-logical responses, and partly due to the lack of a common background of experiences. The child's association time is longer.

The Kent-Rosanoff Test

Certain special conditions, such as insanity and emotional states produce characteristic variations in type of association. For example, the appearance of incoherent responses, neologisms (i.e., new word forms created at the moment), and perseverative responses is so characteristic in dementia praecox patients as to have diagnostic value. Kent and Rosanoff devised and standardized a free association test, consisting of 100 common stimulus words, to be used for diagnostic purposes with the insane. They established norms by giving the test to 1,000 normal individuals and recording and classifying their responses in accordance with their communality. For example, to the stimulus "table," the response "chair" was given by 267 of the 1000 subjects. This response is therefore assigned a communality value of 520, and a table of values is thus constructed on the basis of which the performance of any individual can be evaluated as to its communality. Too wide a departure from these established norms is considered diagnostic, though not necessarily of insanity. A further analysis of the specific response words brings out the type of disturbance from which the subject is suffering.

Free Association Techniques in Diagnosis

Besides the purpose to which Kent and Rosanoff applied the free association technique, two important uses are (1) that of detecting emotional complexes; and (2) that of classifying persons in accordance with their personality type.

Discovering Complexes. — Associations are subject to the *general* laws of association; but they are also to be explained in terms of individual sets or attitudes which the subject has recently acquired, often of an emotional sort. These attitudes may be unknown to the subject himself so that he is unable to reveal them to the experimenter; or they may be deliberately suppressed by the subject in case he is guilty of a crime or trying to cover up his knowledge. In such cases, the free association test may be used to detect or uncover such material in spite of the subject's efforts. This is accomplished in the following way. A list of about fifty common stimulus words is presented to the subject, such as those in the Kent-Rosanoff series, among which are scattered about ten " critical " words relating to the suppressed subject matter of the crime or emotional complex. When such a list is presented to the subject, it is possible to determine, by the character of his responses to the critical words, what is in his mind. (1) A delayed response, giving an excessively long reaction time to a critical stimulus, shows hesitation and conflict. (2) A failure to react signifies inhibition. (3) Sometimes the stimulus is apparently misunderstood, even though spoken distinctly, and this is usually caused by the subject's confusion or surprise. (4) Repetition of the stimulus word by the subject. (5) Various peculiarities in the subject's behavior in reacting, as stuttering, blushing, speaking in an explosive manner or in an excessively low tone. (6) Peculiarities in the response word given, as non-logical relationship to the stimulus, or a resort to superficial connections on the basis of sound or perseveration. (7) Obvious changes in responses to critical words when the test is repeated.

Usually the association test is accompanied, for diagnostic purposes, by instrumental techniques for recording implicit bodily reactions. For example, the so-called lie detector may utilize the breathing curve, the blood volume and blood pressure curves, and the psychogalvanic reflex. The apparatus has been described elsewhere.

Criticism of the association technique may be offered on the ground that no one of the so-called " complex indicators " offers really crucial evidence. But taken in combination they at least suggest a basis for further probing by other means and are valuable in narrowing the field of investigation. As final evidence, their use is unwarranted.

Classification of Association Types

Some attempts have been made to classify individuals on the basis of the type of response which they most frequently give. Thus Jung has contributed a well-known classification consisting of two main types — the egocentric and the objective — and certain subtypes. Wells divides responses into the following five groups: (1) egocentric, (2) supraordinate, (3) contrast, (4) miscellaneous logical relations, (5) verbal habit. But in this field as in other fields where an attempt has been made to establish rigid types, experiment has shown that the majority of individuals do not belong to any single type but fall into a common mixed type.

The Laws of Association

What light has the association test thrown on the laws of association? The general effect has been to substantiate those descriptive categories already formulated, and to point to the necessity of expanding them to take in a larger number of categories of the logical sort. However, it is necessary to distinguish between " logical " and " psychological " categories. For example, supraordination, contrast, etc., are reducible to a common psychological basis; and categories like " emotional," " matter of fact " and " verbal " can hardly be used in formulating laws. The great difficulty in classifying associations is that a particular association will permit of several different classifications.

RESULTS OF CONTROLLED ASSOCIATION EXPERIMENTS

In the free association experiment the laws of association are assumed to operate without restriction, and the train of thought is dependent on the relative strength of associations formed sometime in the past. But in controlled association there is always a present " control " operating to direct the train of thought in prescribed channels. This control, which is imparted by the directions of the experimenter, constitutes a " set " or " determining tendency " or " aufgabe." There is some reason to believe, both from introspective evidence and from objective studies, that such " sets " are exerted through muscular attitudes or tension patterns adopted by the subject. One of the most careful studies of " set " in association is that of Mark A. May. He gives introspective evidence of various specific motor adjustments involved in getting set, which answer closely the suggestions of James. Washburn has developed this hypothesis to its ultimate conclusions in her motor theory of consciousness. For example, suppose that the subject is instructed to respond by opposites to a long list of words. In the process of reacting the subject very soon loses the conscious, deliberate thought, " I must give an opposite," and passes over into an automatic stage, in which the set is implicit. It is probable, though not certain, that the control is now exerted in terms of some static postural neuromuscular attitude which is unaccompanied by specific conscious thought.

One important experimental finding is that controlled association times are shorter than those of free association. Moreover, the more rigid the nature of the controlling set, the shorter the reaction time. For example, Woodworth and Wells report an average reaction time for adult college students on the opposites test of 1.11 sec., P.E. .04, with a range from 0.85 to 1.40 for the easy stimulus list. This can be compared with the average free association range of 1.5 sec. to 2.7 sec. Association times for color naming, obtained by Cattell, are still shorter. Apparently the interference caused by the arousal of rival tendencies delays free association and is removed by a limitation in the number of possible responses allowed.

The value of the controlled association technique lies in the fact that it offers a sensitive test of differences in mental performance between individuals and within the individual resulting from factors such as intelligence, age, fatigue, drugs, etc. The present day intelligence tests are modifications of controlled association tests and most experiments in the field of mental work and fatigue employ a controlled association technique.

EXPERIMENTAL WORK ON DISSOCIATION

In a sense, all the work on forgetting constitutes an experimental attack upon dissociation. The laws of forgetting summarize the conditions under which dissociation of particular material normally occurs. But we have available, in addition, many abnormal forms of dissociation, the study of which will ultimately throw considerable light on the process. Thus far their investigation has been chiefly left to abnormal psychology, and few rigidly scientific experiments have been attempted.

Mental Disease. — Amnesias of various sorts, occurring as a result of emotional traumas, divided personalities such as those reported on by Morton Prince, hysterias involving sensory or motor or ideational dissociations, as described by Janet, deliriums and trances, and the various aphasias, all offer excellent opportunities for studying the direction, intensity, and extent of dissociation. Thus far, however, the evidence is chiefly of the anecdotal and case study sort.

Special Phenomena. — There are certain states occurring in normal individuals which offer opportunity for studying dissociation at a purely functional level. Dreams and somnambulisms, absent-minded behavior, automatic acts, including automatic writing, and, most promising of all, hypnotic phenomena, fall in this class. Psychoanalysis has surrounded the dissociated state of dreaming with an unnecessary and confusing mass of auxiliary concepts involving too ready an assumption of dynamic forces to explain simple dissociated patterns. Their reasoning is too armchair. Much more profitable are studies of the sort begun by Klein, in which the patterns of the dream are experimentally controlled and varied under laboratory conditions, or where the dream content is systematically checked against the subject's previous history with adequate statistical controls exercised.

Hypnosis has only recently emerged from the category of parlor and vaudeville tricks, as a result of the work of Clark L. Hull and others, who have, on the one hand, made a strenuous effort to perfect and standardize the hypnotic technique, and on the other hand, applied the technique to the problems of memory and forgetting. Practically every problem of memory can be repeated with profit using hypnosis. Especially important will be the applications of the technique to interference phenomena, such as the problem of retroactive inhibition. Another fruitful application can be made to the problem of reintegration of dissociated material.

Drug Effects. — The possibility of producing artificial dissociations by the use of drugs has scarcely been sampled as yet. Thus far the drug experiments have been designed to discover the properties of the drug rather than to study mental functions analytically, with the notable exception of experiments in cutaneous sensation. A serious drawback to careful work at present is the meagreness of our knowledge of the physiological and biochemical effects of drugs on the system. But, with growing knowledge in this direction, the possibilities seem infinite for controlled analytical experiments in dissociation of mental functions. Certainly the technique should prove more precise and quantitative, more certain, and more easily applicable than hypnosis.

REFERENCES

Blase, Irene. Fatigue effects in free association. Univ. of Chicago. Ms. Thesis unpublished, 1927.

Cattell, J. M. Ueber die Zeit der Erkennung und Benennung von Schriftzeichen, Bildern und Farben. Wundt's Philosophische Studien, 1883–88, Vols. 2, 3, 4.

Dunlap, K. The Johns Hopkins Chronoscope. *J. Exper. Psychol.*, 1917, 2, 249–252.

Hull, C. L. Quantitative methods of investigating hypnotic suggestion. Pt. I. *J. Abn. & Soc. Psychol.*, 1931, 25, 390–417.

Janet, Pierre. The major symptoms of hysteria. N. Y. 1920, Macmillan.

Jung, K. See Wells, F. Practice effects in free association. *Amer. J. Psychol.*, 1911, 22, 1–13.

Kent, G. H., and Rosanoff, A. J. A study of associations in insanity. *Amer. J. Insanity*, 1910, 67, 37–96, 317–390.

Klein, D. B. The experimental production of dreams during hypnosis. *Univ. Texas Bull.*, 1930, No. 3009, 1–71.

May, M. A. The mechanisms of controlled association. *Arch. Psychol.*, 1917, No. 39, 1–74.

Meumann, E. Intelligenzprüfungen an Kindern der Volkschule. *E. Pd.* 1, 1905, 89–101.

Otis, M. A study of association in defectives. *J. Ed. Psychol.*, 1915, 6, 271–288.

Prince, M. The dissociation of a personality. N. Y.: Longman's Green, 1906, pp. 1–569.

Rosanoff, A. J., and Rosanoff, I. R. A study of association in children. *Psychol. Rev.*, 1913, 20, 43–89.

Washburn, M. F. Movement and mental imagery. N. Y. 1916, Houghton Mifflin, pp. 252.

Wells, F. L. Some properties of the free association time. *Psychol. Rev.*, 1911, 18, 1–23.

Wells, F. L. A preliminary note on the categories of association reactions. *Psychol. Rev.*, 1911, 18, 229–233.

Woodworth, R. S., and Wells, F. L. Association tests. *Psychol. Monog.*, 1911, 13, No. 57, p. 85.

CHAPTER XVIII

IMAGERY

THE NATURE OF IMAGERY

IT HAS been pointed out that one of the important forms of recall is the memory image. The study of images in psychology has undergone a decline in recent years, partly because of the practical difficulties inherent in a type of experiment which is exclusively subjective, partly because of the failure to formulate significant problems, but chiefly because of the doubt which has been cast on the reality or importance of the phenomena by certain recent psychologists. Whereas images were once thought to constitute the chief form of memorial and imaginal representation, and hence the chief kind of " idea," now they are looked upon as unessential to conscious processes. Many psychologists deny the presence of imagery in their own thinking and are sceptical of its presence in the thinking of others.

On the other hand, confidence in the reality of imagery is being somewhat restored by the discoveries concerning the related phenomenon of the eidetic image under the leadership of Jaensch. Much more objective and convincing proofs have been brought forth for the reality of the latter phenomenon. Some former sceptics have been won over. More will be said about eidetic imagery elsewhere.

Image and Percept Distinguished. — An image is defined as sensory content which is not accounted for in terms of the present pattern of peripheral stimulation. The assumption is therefore that it represents the rearousal of sensory impressions which were formed by previous sensory stimulation. This rearousal is supposed to take place centrally, and to be made possible through association. For this reason images have been called " centrally aroused sensations."

Images are qualitatively different from percepts in certain ways. They are less vivid and distinct, less clear in outline, more fleeting and changeable, and require effort to maintain. They are differently localized by different subjects, some placing them in the present field of vision at normal distances from the eyes, others localizing them in the head, or eyes, while some detach them from all present surroundings, placing them in a space of their own. For some, they are totally unlocalized.

Neural Basis of Imagery. — Nothing definite is known of the neurology of imagery though many speculations have been made. Roughly two theories are held, the central or the peripheral. According to the former, which is most widely accepted, only the central process is involved. For example, if an auditory stimulus, in arousing a psychological reaction, not only excites impulses in the auditory center, but also, through preëstablished associational connections with the visual center, excites them indirectly in the visual cortex, visual images will be experienced. Thus if one hears the rattle of a passing automobile, he may have a simultaneous visual image of a Ford car.

On the other hand, Watson has claimed that the process probably results from the peripheral stimulation of the retina or other sense organ, but from within by a process of neural drainage, rather than from physical stimuli in the environment. The latter theory violates the principle of unipolarity of the neural tract and seems an unnecessary attempt to force the process out to the periphery, when the other hypothesis is plausible enough.

Experimental Proofs of Imagery. — Since images are private experiences, and since we must therefore depend entirely upon the subjects introspective report as to whether he has or has not experienced an image, it is extremely difficult to devise adequate tests of the phenomenon. Naïve subjects are likely to confuse thinking with having images, and to assume that, because they can think clearly or remember accurately some event, that they must therefore have images.

They may very well be using other sorts of thought representatives. Also, a common source of error is to confuse the dominant characteristic of an object with the mental process used in thinking about it. Merely because violins are sound producing instruments, we are not justified in taking it for granted that we must think of them in terms of auditory imagery.

One of the earliest systematic attempts to study imagery is that of Francis Galton in 1880. His method was to distribute a questionnaire in which the subject was asked to call up an image of some scene, as the breakfast table, and report on its clearness, vividness, and accuracy of detail. All sorts of professions were represented — artists, musicians, business men, lawyers, scientists, etc. He discovered, to his surprise, that many subjects reported little or no imagery. An artist of the Royal Academy reported that he experienced no images in his work. Others claimed to have very lifelike images practically as clear as percepts. Certain conclusions stand out from Galton's work. Scientists as a class are deficient in imagery. This Galton attributed to the habit of abstract thinking in which mental content is stripped down to a bare minimum. Children are rich in imagery. Women report more images and a greater variety than men.

Among other things, the work of Galton raised the question of imagery types. Theoretically every person is capable of having images from particular modalities, such as vision or kinaesthesis. Proceeding on this assumption, psychologists classified persons in accordance with their predominant type of imagery, into visualizers, audiles, tactiles, etc. Further investigation proved that the great majority of persons do not belong to any one type, but rather fall into a mixed type, possessing all kinds of imagery to about an equal degree. One of the best proofs of this is the proof by correlation. If exclusive types are the rule, then there ought to be a very low correlation between the clearness of a subject's imagery in different sense modalities. The contrary was found to be the rule. Correlation coefficients from .46 to .85 were obtained by Betts. Those who ranked low in one modality did so for the others as well, and vice versa. This does not deny the fact that a small number of extreme cases have been found whose images are confined to a single modality.

Among the more prominent of the experimental procedures for studying imagery are the following:

The Association Method. — Various forms have been used. One method is to find how many objects a subject can name in a given time, having a characteristic visual or auditory or other quality. It is falsely assumed that he will name the most in the field of his imagery type. Another method is to compare the speed of learning by eye, ear, etc., again falsely assuming that a thing learned through the eye is necessarily learned visually. Another is the Letter-square method in which the subject is presented with a series of letters or numbers arranged in a square, and, having learned them in a given arrangement, must recall them in a different one. The test obviously rests on a false assumption.

Confusion Test. — This type of experiment differs from the preceding in that it is not designed to determine imagery types, but rather to determine the tendency to objectify images. It was originated by Külpe, who seated subjects before a screen, illuminated from behind, on which faint colored patches were thrown. Part of the time the stimuli were present, and part of the time absent, and the subject had to judge whether, at a given time, the stimulus was present or absent. The subjects were frequently confused as to whether the stimulus was or was not present, demonstrating the presence of some representative, presumably an image in its absence. Perky performed a similar experiment in the Cornell laboratory, using, among other stimuli, a banana, hazily outlined against a screen. The subjects were told to call up a visual image, and the suggestion was given that the banana on the screen *was* their image. The majority were fooled, thus supposedly demonstrating that images are so similar to percepts as to be indistinguishable from them. But little is known about effects produced by suggestion, and the conclusions are rendered a bit doubtful by that fact.

Afterimages of Images. — One of the most convincing proofs of the physiological reality of images is contributed by the following experiment which has been tried by Downey among others. Using a naïve subject, she asked her to call up images of colored objects on a white background, hold them for a few seconds, and then close her eyes and report what she saw. Definite afterimages of the images called up were reported, sometimes positive, sometimes negative, in which case they obeyed the laws of complementary relationship found in afterimages of real colored stimuli, i.e., blue afterimages of yellow images and green afterimages of red images. The same subject found that when she projected her colored images on real backgrounds of complementary hue, the result was a complementary gray.

Eidetic Imagery. — Although investigators of eidetic imagery take considerable effort to differentiate between ordinary imagery and the eidetic type, nevertheless the existence of the latter tends to strengthen the claims of the former for recognition as a bona fide phenomenon.

The study of eidetic types has been carried on in Germany prominently by Jaensch, and in America considerable work has been performed by Klüver. According to these investigators, an eidetic image is actually *seen* by the subject, not imagined, and has perceptual clearness and definiteness. Many ingenious tests have been devised to check on it. For example, an eidetic colored boy who had briefly observed a crocodile with open mouth was asked a year later how many teeth it had. He counted them from his mental image and reported the correct number. Not all persons possess eidetic imagery. It is far more prevalent in children than in adults. It is found more frequently in certain geographical locations, as, for example, the southern states. This latter fact is attributed to dietary conditions. Kroh reported that 61 per cent of a group of 379 high school pupils, from 9 to 19 years of age, in Marburg, were eidetic. G. Allport, in an excellent discussion of eidetic imagery, notes the following differences between eidetic and memory imagery: (a) it is pseudo-perceptual in character; (b) its clearness is independent of organization such as is necessary for definiteness in ordinary memory images; (c) it is more accurate in detail and coloration, which may be either positive or negative like afterimages; (d) it requires rigid fixation over a considerable time, and must be projected against a favorable background. It differs from afterimages in that (a) it reproduces complicated objects, of more than one dimension, (b) it persists for an almost indefinite time, (c) it can be voluntarily aroused at any time, (d) it is selective as to subject matter, and depends on the subject's interests, and (e) it is subject to voluntary control. But it is like afterimages in that it always appears in visual space, is accompanied by eye tension, and can be positive or negative.

The mid-position which eidetic imagery occupies between the afterimage and the memory image proper has led investigators to postulate a series of steps, possibly genetic, from the afterimage, through the eidetic to the memory image.

IMAGERY IN HALLUCINATION AND DREAM

Practically the only essential difference between normal waking imagery and that of hallucinations and dreams lies in the fact that the latter images are mistaken for percepts and accompanied by belief in their reality. They are probably more vivid and detailed than ordinary images, also.

Hallucinations have not been experimentally studied in a systematic way, since it is difficult to produce them voluntarily in the waking state without the aid of drugs. They may be produced during hypnosis by direct or indirect suggestion. Characteristic hallucinations result from eating the mescal bean, smoking opium, etc. Those occurring without drugs are usually experienced in connection with severe emotional conflict, or anxiety, or delirium. Dreams are hallucinatory images experienced during sleep.

Dreams have acquired experimental interest from psychoanalytical doctrine. Recently the attempt has been made to control the content of dreams by controlling the stimuli, as in the work of Klein. Dreams have been found to be of two distinct sorts, presentative and representative. The former are equivalent to distorted percepts of external stimuli acting upon the organism at the time. Noises in the sleeper's environment, objects in contact with the skin, positions of the body, temperature stimuli, etc., as well as internal conditions such as a distended bladder, give rise to experiences which constitute distorted percepts. These distortions are apparently subject to definite laws which have not yet been formulated.

The other class of dreams, called representative, are not directly determined by present environmental stimuli; but are perseverative in character because they represent the recurrence of the thoughts, emotions, attitudes and feelings of waking life. They sometimes represent emotional attitudes of long standing which can even be traced back to early childhood. The wish fulfilling dream, and the nightmare expressing anxiety attitudes, are common forms. Psychoanalysts have dogmatized about dreams, to the effect that they are predominantly motivated by sex needs; but there seems little justification for the dogma. They have also called attention to the fact that the various inhibitive attitudes of waking life are not absent in sleep, and that some of the typical distortions of the dream content result from the arousal of these inhibitive attitudes. They therefore distinguish between a latent content and a manifest content in the dream. They err chiefly in assuming that the latent content is always sexual, in the absence of more convincing proof.

A general criticism of the psychoanalytical technique of dream analysis is that it is subject to all the pitfalls of naïve introspection, as suggestion, distortion, forgetting, language error, etc., and in addition starts out from a preconceived dogma that all dreams are sexual, and symbolic and that the symbolism is universal. Dream analysis, as a method of studying imagery and association, can only prove valuable through the application of rigid experimental controls and statistical analysis. An example of the use of such methods is the preliminary study of Selling on the dreams of 200 inmates of a state corrective institution for boys. The subjects were asked to describe their dreams and the content was analyzed for the frequency of various determining tendencies. Recurrence of perceptual experiences seemed to be most frequent, and sex as a motive was rare.

THE OPERATION OF IMAGERY IN MENTAL LIFE

A customary classification of images in mental life distinguishes between (a) reproduction or memorial images, and (b) creative imagery or imagination. A third class would be conceptual images, used to carry concepts. But since all percepts employ a background of imagery, it seems to be a universal accompaniment of all cognition. The opposite proposition, however, that thought cannot take place without images is affirmed by some and strenuously denied by other experimenters. The doctrine of imageless thought affirms that much thinking takes place in terms of processes which are introspectible but devoid of imaginal content. Since the answer is dependent on introspection, and since introspective evidence is at variance, the problem has been largely dropped and is no longer a live current issue.

The question of the existence of generic or composite images, corresponding to the ability to think in terms of general or class concepts was once debated but the introspective evidence is almost universally negative. When we think of dogs in general we do so in terms of a particular image, if an image is used at all. Koffka however gives experimental data of an introspective type which point to the possibility of generalized or non-particularized images. For example, images of statues were reported which were neither man nor woman and an image of a coin with no particular denomination. However, the function of the image was dictated by the meaning which was assigned to it, and this was independent of its form.

The problem of the relation of kind and amount of imagery to the efficiency of thinking was attacked by Betts. He compared imagery ratings with college grades. A slight negative correlation was obtained between imagery and scholarship. Type of imagery, whether chiefly of one or another modality, seems also to have little bearing on the efficiency of thought. Imagery may or may not accompany perception, memory, judgment, and conation, but whether it does or not it has little bearing on the efficiency of the process but rather comes in as an extra fact, either concomitant with or subsequent to the essential process. Woodworth has summarized the function of imagery in the following terms, " In contrast with older theories which sought the function of the image beyond itself, we would say that the function of the image is to furnish that which is contained within itself, namely, sensory qualities and general pictorial effects."

REFERENCES

Allport, G. W. Eidetic imagery. *Brit. J. Psychol.*, 1924, 15, 99.

Betts, G. H. The distribution and functions of mental imagery. N. Y. Teachers College, 1909. Columbia Univ.

Downey, J. E. On getting an afterimage from a mental image. *Psychol. Rev.*, 1901, 8, 42–55.

Galton, Francis. Inquiries into the human faculty and its development. N. Y.: E. P. Dutton & Co., 1908.

Jaensch, E. R. For Bibliography, see Klüver, H. Studies on the eidetic type and on eidetic imagery. *Psychol. Bull.*, 1928, 25, 69–104.

Jaensch, E. R. Eidetic imagery and typological methods of investigation; their importance for the psychology of childhood, the theory of education, general psychology and the psychophysiology of human personality. N. Y. Harcourt Brace Co., 1930.

Klein, D. B. The experimental production of dreams during hypnosis. *Univ. Texas Bull.*, 1930, No. 3009, 1–71.

Klüver, H. Studies on the eidetic type and on eidetic imagery. *Psychol. Bull.*, 1928, 25, 69–104.

Klüver, H. An experimental study of the eidetic type. *Genet. Psychol. Monog.*, 1926, 1, 71.

Koffka, K. Zur Analyse der Vorstellungen und ihre Gesetze. Eine experimentelle Untersuchung. Leipzig. Quelle & Meyer. 1912, pp. 1–392.

Kroh, O. Subjektive optische Anschauungsbilder bei Jugendlichen. *Zeitsch. f. päd. Psychol.*, 1922, 23, 40.

Külpe, O. Ueber die Objectivirung und Subjectivirung von Sinneseindrücken. Philosophische Studien. 1902, 19, p. 508.

Perkey, C. W. An experimental study of imagination. *Amer. J. Psychol.*, 1910, 21, 422–452.

Watson, J. B. Image and affection in behavior. *J. Phil. Psychol. & Scient. Method.*, 1913, 10, 421–428.

Woodworth, R. S., and Poffenberger, A. T. Experimental psychology. An unpublished manuscript. 1920. Columbia Univ. p. 176.

CHAPTER XIX

ABSTRACT THINKING

WITH THE abandonment of the dogma that all thinking occurs in terms of images, interest was aroused in other forms of representation. Pragmatism, by denying that the idea is a mere pictorial representative of its object and insisting that the only essential qualification of ideas is that they perform a substitute function in the absence of the particular percept which they stand for, assisted the cause. Ideas were then identified in terms of their function rather than their form.

Idea Defined.—An idea is any process which serves as a substitute stimulus in thinking. Ideas symbolize objects and situations in their absence. Ideas may therefore have many different forms, but in terms of function they are either memorial or imaginal or conceptual. Memorial ideas have the function of representing concrete past situations and imaginal ideas represent hypothetical situations. Concepts stand for generalized rather than particular objects and situations and are therefore abstract. Some concepts are hypothetical, as the physical concept of "ether"; others are mere generalized percepts, as the concept "dog." Because of their generalizing function, in which some feature is abstracted, concepts are usually schematic in form.

THE STRUCTURE OF IDEAS

THE chief method of investigating ideas is necessarily introspective, though some studies of an objective type have been performed both on humans and on animals. The following forms have been reported:

Images. — Already described.

Imageless Thoughts. — The German psychologist Külpe and his Würtzburg students, chiefly Bühler, precipitated the controversy which was carried on in America by Woodworth and Ogden, among others. These psychologists and their subjects reported that meanings could be carried without any imaginal or sensory content. James had anticipated the concept in his "transitional states of consciousness" and his "vague feelings of *if,* and *but.*" Titchener and his subjects reported no such contentless ideas. The nature of the content in these imageless thought processes was reported as indescribable in concrete terms, even though its presence was an undeniable fact of introspection.

Sensory Content. — Experiments performed by introspectionists have brought to light various sensory processes, as representatives or carriers of meaning. Meanings of a conative sort have appeared as strain sensations and other kinaesthetic processes. Depth in visual space is in part a meaning contributed by experience of the eye strain involved in convergence. As a matter of fact the diagrams drawn on a blackboard by a lecturer give rise to visual sensations whose purpose is to carry meaning, and hence to perform the function of ideas.

Implicit Movements. — The doctrine of subvocal speech as the chief form of thinking has been championed by Watson. In its developed form, the theory is not confined to implicit movements of the vocal mechanism but includes all sorts of movements, gestures, and muscular attitudes of the body which are assumed to carry on the process of thought. In its broadest application it includes glandular as well as muscular processes, in short, the entire periphery, and hence it may be spoken of as the peripheral aspect of thinking. Since the theory in its original form assumed that actual measurable movements occurred, it offered the possibility of objective verification, provided delicate enough instruments could be devised to make the records. Several experiments have been performed, among which are the following: —

Implicit speech movements

Early studies are reported by Curtis and by Courten, which substantiate the presence of tongue and laryngeal movements in thinking. The former applied a tambour to the larynx while the subject recited or whispered or read silently from a book. Fifteen out of twenty subjects showed movements part of the time, while the rest failed to show them even in whispering. The latter used a rubber bulb on the tongue with tambour attachment. He invariably got movements, which differed with the matter thought about.

Wyczoikowska's Experiment.—In 1913, Anna Wyczoikowska obtained kymographic records of tongue movements of subjects engaged in thinking of a familiar verse, or of a melody, or of the words "experimental psychology," or in hearing these spoken. Her apparatus consisted of a flat wine glass fitted over the end of the tongue, and tambour attachment. Characteristic curves were obtained showing tongue movements. Apparently no attempt was made to correlate these with the movements of the tongue made in actual speech.

Pintner demonstrated that articulation may be suppressed in silent reading without interfering with comprehension. His method was to inhibit articulation by compelling his subjects to repeat la, la, or numbers while reading.

Reed obtained kymographic records of tongue movements, by means of a sensitive rubber bag attached in the mouth. Definite tongue movements in silent reading comparable to those in whispering were obtained from some, but not all, of his subjects.

Clark more recently obtained records of tongue and laryngeal movements simultaneously, by means of a rubber bulb on the tongue, and a tambour against the larynx. Both laryngeal and tongue movements were occasionally secured but not consistently.

Thorsen used an apparatus devised by Lashley for obtaining tongue movements, which is a modification of Sommer's "movement analyser." It employs a small metal suction cup attached to the tongue and connected by a fine wire running between the teeth to an external lever system, with recording needles, which amplifies both horizontal and vertical tongue movements over three times. In this way respiratory and swallowing movements were eliminated. Thorsen concluded that, since tongue movements did not occur universally in thought, nor correspond in form to the movements of overt speech, nor show a consistency among themselves of over ten per cent when the same thought was repeated, they could not be essential to the thought. She also observed that the movements occurred more readily under distraction and under a speed set, and concluded that they depended on conditions of nervous irradiation and muscle tonus.

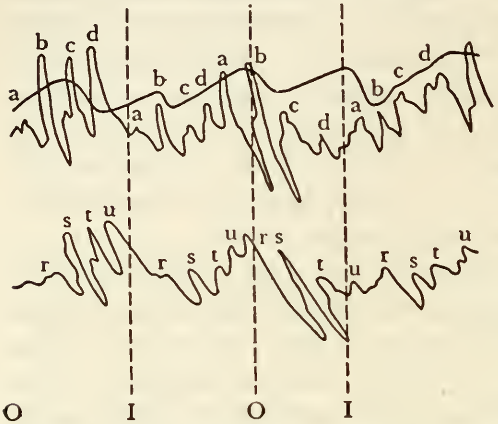


Fig. 80. Kymographic records of tongue movements in whispering and silently thinking, "Jack and Jill went up the hill," compared

The section marked O gives the overt movements; that marked I gives the internal speech. The top line represents breathing; the next, horizontal movements; the lowest, vertical movements.

From Thorsen, in Journal of Experimental Psychology, 1925, 8, p. 17, Fig. 4.

A crucial experiment would be one in which the laryngeal mechanism was temporarily paralyzed. Could a subject in this state carry on thinking?

Other musculature

Since the theory admits that any bodily musculature may be used, it is necessary to explore further than the vocal mechanism.

Eye movements. — The eye muscles may serve the same purpose. It is possible that movements of convergence or localizing movements are meaning carriers in the absence of subvocal speech. Some persons report their thinking as principally verbal while others report considerable visual imagery. Perhaps the latter type use eye movements as meaning carriers. Few studies have been reported in which a systematic study of eye movements in thinking was made. Unpublished results are reported by Lashley pointing in a negative direction. On the other hand, Stoy obtained interesting corroboration of the general doctrine in a study of eye movements performed while mentally solving spacial and non-spacial problems. He measured the number and extent of the horizontal eye movements by viewing the subject's eye through a keratometer, a tubular instrument whose lens magnifies the eye and is equipped with a millimeter scale for estimating the amplitude of iris movements. The subjects were given two types of problems, (a) spacial, as for example: "Imagine that you are on top of a building at State and Madison Streets. You can see the whole city. What fraction of Chicago would you see west of State Street?" (b) non-spacial, as the following: "No news is good news," therefore all news is bad news. Is this true or false? Why?" In this way Stoy obtained from fifty subjects records of the number of movements, the largest single movement and the time on each of 11 spacial and ten non-spacial problems. The mean largest movement on the spacial was 2.4 mm, and on the non-spacial was 1.7 mm, a statistically significant difference. Significantly more movements occurred in solving the spacial problems. Individuals showed either a consistently high or consistently low record on eye movement. There was a slight positive correlation of .25 between size and frequency of eye movements and instructor's judgments of ability in architectural drawing, though none existed between number and size of movements and ability to solve spacial problems.

Using an apparatus of the Dodge type for photographing eye movements, Bills and Nell obtained continuous films of eye movements of subjects (1) while they were reading a short poem placed in front of them, and (2) while they were recalling the same poem from memory. Approximately fifty percent of the subjects showed eye movements under the second condition which were roughly similar to those in the first. But the other fifty per cent showed practically no movements of any sort. The implication is that persons differ in their thought mechanisms to such an extent that no rule can be laid down. But the nature of the mechanism has little bearing on the efficiency of their thinking process which suggests that the essential factor is not so much the particular outward form of thought, i.e. the meaning carrier, as it is the thing meant.

Bodily attitudes. — There remain the various other muscular attitudes and static tensions which are experimentally proved to accompany thinking, and to add materially to the efficiency of thought, though apparently not because of any direct meaningful relation to the content thought about. Introspective evidence, such as Jacobson's experiments on inhibitions of sensations, showing that kinaesthetic strains accompany each act of thought, led Washburn to formulate a motor psychology of thinking which is set forth in her book "Movement and Mental Imagery." That tensions habitually accompany all thinking and mental effort has been demonstrated by Golla who studied action currents, galvanometrically, from many different muscles. This heightening of muscle tonus increases rapidly during prolonged mental effort and declines with the onset of mental fatigue. Jacobson has also recently obtained photographs of action currents from many specific muscles during mental work, showing not only that thinking is normally accompanied by widespread tensions, but that it is impossible for subjects to relax while thinking. White, in studying the relation of the electrical resistance changes registered by the galvanometer to muscular tensions, found that subjects engaged in silent multiplication showed a greater drop in resistance than that caused by strong voluntary contraction of the arm. Stroud, by means of a special apparatus designed to register jaw tension and hand tension on the stylus while learning stylus mazes, demonstrated a correlation between difficulty of the problem and degree of tension. Bills established the fact that muscular tensions aid the efficiency of the mental process by having subjects work under two conditions: (1) the normal degree of bodily tension; and (2) heightened tension caused by voluntarily squeezing a dynamometer with a pressure of about fifteen pounds. Reliable differences were found showing heightened efficiency in learning and controlled association under the latter condition. Freeman demonstrated that the effect varies with the amount of tension employed.

The contemplation of all this work on the peripheral aspect of thought, however, leaves one with the conviction that little will be learned about the intrinsic nature of thought until it can be studied in terms of its ultimate mechanism, the central nervous process.

MEANING

The concept of meaning is one of the most troublesome in psychology. Due to the philosophical implications of the term, many psychologists have insisted that it has no place among psychological concepts. Others have distinguished between meaning as "relationship," and meaning as structure or "process." Titchener at one time insisted that meaning as process consisted of an imaginal context or fringe of imagery. Thus the meaning of icicle is embodied in the kinaesthetic imagery of shivering, the cutaneous imagery of coldness, etc. But the meaning relationship he insisted was logical, not psychological. James and Calkins insisted that relational elements form a part of the content of consciousness as non-imaginal "processes." Certain behaviorists have insisted that the meaning of any situation, psychologically speaking, is the response made to it, thus identifying meaning with motor response, or way of responding. If this is extended to take in incipient motor attitudes it fits the point of view of motor psychology in general. Some psychologists, as Hollingworth, have identified meaning with the "act of association" or redintegration, whereby a *part* of the original stimulus situation is capable of being responded to as though to the *whole*. Carr has identified meaning with "inferential knowledge," i.e., that knowledge of some absent fact which we derive from some present fact.

It is plain that in all these definitions the factor of "reference" is implicit. Meaning is reference or the function of referring, and it makes little difference how the referring is accomplished. Meaning is thus a *function* not a *structure* of thought. And, as such, it has a place in a functional psychology which distinguishes its units in terms of functions rather than structural qualities. There is no real objection to the assumption that some meanings may be negotiated below the level of consciousness in terms of unconscious cerebral processes.

LANGUAGE AND CONCEPTS

So-called abstract thinking involves meanings which are generalized, applying to a class of situations never to a particular situation. The tool of abstract thinking is the concept. A concept is not to be understood as any particular sort of structure, however. A concept may be any psychological process whatsoever which performs the function of carrying a generalized meaning. Students of the development of concepts have found them to be closely related genetically to the development of language. The primary function of language is to communicate meanings to others. These meanings may be concrete and particular or they may be abstract and general. The important point is that, in the process of developing a system of signs or symbols to convey meanings to others man has at the same time furnished himself with an indispensable tool to use in manipulating meanings in his own thinking. It is improbable that any great development of abstract or general thinking could have taken place without the possession of the language tool. Language, even in concrete perceptual situations, strips off the unessential factors and seizes upon the important element. A study of the historical development of written language shows that it has gradually changed from a system of concrete pictures of objects to a very schematized code. Spoken language has probably undergone some analogous process. " Oral speech and picture language coalesced to form one language system, when drawings and graphic signs were employed to represent, not objects, but sounds in the oral speech system." The result is the capacity to express thoughts schematically. This has in turn reacted upon thought, so that by inner speech it is possible to think schematically. Language, defined as a system of expressive signs, has therefore acquired a double function: that of conceptual analysis and synthesis, and that of communication of meanings.

Psychological experiments in language have followed three main lines, (1) the study of speech development, (2) the study of reading and writing, and (3) the study of language disorders. The first class includes the investigations of children's vocabulary, sentence formation, etc., and the correlative ability to form concepts and solve problems. Terman has recognized that the chief factor in development of intelligence is language growth, and the Stanford Revision of the Binet tests gets at ability to understand and use language symbols properly. The second field includes those studies which have been made of reading habits. These experiments were largely made possible by the invention of a technique for recording the movements of the eyes in reading. The earliest methods, employed by Huey, proved extremely clumsy. He used a lever attached directly to the cornea, and recorded the movements kymographically. An improved device was that of a spot of Chinese white placed on the cornea and photographed on a sliding camera plate. With the invention of the moving film a method has been devised which is universally used in this work. It is largely the invention of Dodge. A beam of light is projected on the subject's cornea in a dark room. When the subject's eye moves, the beam of light moves almost proportionately, due to the fact that the radius of the cornea is much smaller than that of the eyeball. These movements are photographed on a continuously moving film. A reference line is obtained from another beam of light located at a stationary point on the outer edge of the eye, and this beam is interrupted regularly by a vibrating tuning fork so that the time of movements and pauses can be estimated. With the use of this improved technique a series of studies has been made by Judd, Buswell, and others, which throw light not only on the verbal, but also on the number system. These studies show, first, that in trained readers, the eyes move forward in a series of rapid jumps with fixation pauses at relatively regular intervals. Not every letter nor even every word is fixated, but the material is grasped in phrases or large groups. Untrained readers make many pauses and backward movements, showing impartial comprehension and difficulty with forms. Reading difficulties can be detected and speed of comprehension improved by study of these eye records and the teaching of correct habits.

Fig. 82 is a record of the eye movements of a good reader and of a poor reader, taken from a study of Buswell on the relation between eye perception and vocal response.

One discovery is that the ability to read silently with speed and to grasp meaning effectively is hindered in development by oral reading. The reason is that vocalization is a slow process and that comprehension in silent reading may occur without it. With training, whole sentences or even short paragraphs may be comprehended at a single glance. Whatever implicit mechanism is used in this process, it is quite different from vocalization, and is independent of word units.

Investigations of graphic language, i.e., writing movements, have been made by Judd among others. His apparatus permits a measurement of the amplitude of movement of the various fingers. Another device measures the pressure exerted on the page in forming the different letters. Either a spring supported or air supported cushion lies under the plate on which the writing is done, and pressure is kymographically recorded through a tambour. Another device for getting hand pressure is the "pressure stylus," which contains a spring or an air chamber within the stylus. Pressure exerted on the point is thus communicated

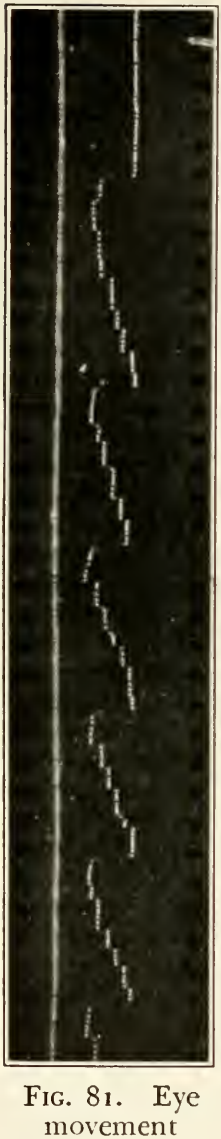


FIG. 81. Eye movement photograph

Courtesy of Dr. G. T. Buswell, Dept. of Education, University of Chicago.

to a tambour and recorded. The results have more practical than psychological significance, though the discovery of inner speech or vocalized accompaniments of untrained writing and its reduction with training throws light on the genetic history of the graphic habits.

The third direction of language investigations has to do with speech disorders. The most important is aphasia, or the inability to comprehend or to use language. The study of this disorder promises to yield results of interest far beyond the limits of language itself. It seems to present a basis for studying the ways in which the sensory motor and central mechanisms of thought are articulated. The various aphasias represent many ways in which the language function may disintegrate. Some of these ways defy analysis in terms of our usual logical a priori categories. A subject may be able to read a word; or it may be pronounced but convey no meaning — a type called alexia. Or he may be unable to recall the name of an object even though he recognizes its purpose. Usually the distinctions are more subtle than this, embracing particular subject matter, or fields of knowledge. Inability to write language is known as agraphia. Aphasias are usually attributed to localized cortical or subcortical lesions, but more

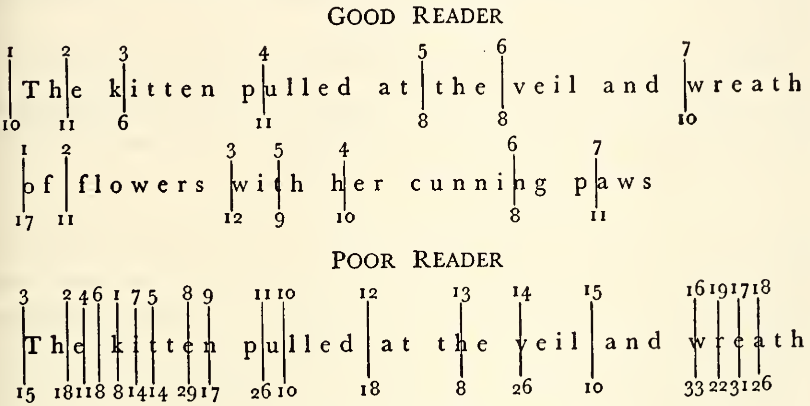


FIG. 82. Eye pauses

The vertical lines represent eye pauses; the numbers at the top of the lines represent the successive order of the pauses; and the numbers at the bottom of the lines represent the length of the pauses in fiftieths of a second.

recent evidence points to a general interference with the adequate functioning of thought rather than the dropping out of specific materials.

Another line of study attacks the problems of reading disability in otherwise normal children. Certain features have been isolated. Left-handedness and left-eyedness as they affect reading; the tendency to read backwards, or reverse letters, resulting in poor spelling; these and similar discoveries of Monroe and others offer fruitful points of departure.

The present attack upon stuttering and stammering as centrally caused, involving some form of central inhibition rather than a defect in vocal mechanics, promises to yield further insight into the thought process.

GENERALIZATION, ABSTRACTION AND CONCEPT-FORMATION

The statement was made, in the discussion of transfer in learning, that transfer is merely a phase of the larger problem of the utilization of what is learned in reacting to subsequent problems. Since no two situations are absolutely identical, it follows that the subject always reacts to certain features of the new situation which are identical with the original stimulus. Presumably this requires a certain amount of abstraction from the whole, though it is not necessary for the process of abstraction to be conscious or deliberate. When a child calls a sheep a " dog " he is reacting to certain features which have come to be identified with the word " dog " in his mind.

It is a further step to generalize on the basis of several such instances, and to build up a generalized concept of dog, as distinguished from particular dogs. Concept formation involves the gradual refinement and clarifying of the generalized idea in terms of both positive and negative instances. When the general concept emerges it may not be explicit, nor capable of precise definition. Hull has shown that capacity for verbal definition is not an essential requirement for making correct responses to generalized concepts. But whether explicit or implicit, the processes of abstraction and generalization are fundamental. And concept formation is an indispensable prerequisite to reflective thought or reasoning.

The process of concept-formation has been studied from various angles. Earlier studies, such as those of Külpe, Moore, Grünbaum, Aveling and Fisher, were studies of the introspective type concerned with process largely, and were of the qualitative sort. Such questions were raised as that of whether general concepts always involve imaginal content or whether they are imageless in structure. Contradictory results were obtained. Moore's subjects found imageless thought content, as did Aveling's. Moore's method was to present rapidly a series of groups of geometrical figures, five in a group, one of which recurred in all of the groups, the others always being novel. The subjects were to decide as rapidly as possible which was the common element, if any, and to press a key to register their reaction time. He found that the essential process, that of perception of the common figure as repeated, was independent of imagery. Grünbaum used a similar method with simultaneous presentation of two groups. But Fisher presented single nonsense forms to her subjects in succession containing common elements. Each form in the series had a name. The subjects were asked to define the group name of the series at the end. She took introspections and always found imaginal elements present.

Another question relates to the anticipatory set or " Aufgabe " which precedes the process of generalization and in terms of which the abstractions are made. Külpe found the process considerably facilitated by this " Aufgabe." No doubt the function of verbal thought in clarifying the " Aufgabe " makes possible a much more rapid generalizing process than could otherwise occur.

All of these studies were concerned with the qualitative side of the generalizing process. Hull, on the other hand, investigated the quantitative side, and set himself the task of determining the relative efficiency of the process of concept formation by different methods. Among the problems raised were (1) the relative efficiency of proceeding from simple to complex versus complex to simple in evolving concepts. This was tested by preparing twelve sets of twelve Chinese characters, each set involving a simple character which recurred and formed the common concept for that particular group. The subjects pronounced a certain nonsense syllable when any one of the characters containing this concept appeared. The characters were presented in a random order, but in the order simple-to-complex or the reverse. Hull found a decided advantage for the simple-to-complex procedure; that is, in order to facilitate the process of abstraction it is better to present the element to be abstracted in a simple setting first rather than a complex one. The accompanying graph, Figure 83, shows the relative rates of concept-formation under the two methods. Moreover, the simple settings are, in general, more valuable for concept-formation than the complex ones. Other principles of concept-formation experimentally established by Hull are: (2) that abstract concepts given to the subject directly show the same functional efficiency as those evolved by the subject from concrete examples; (3) but a combination of the two methods is best; (4) moderate familiarity with many concrete cases is more valuable than great familiarity with a few; and (5) the individual concepts usually evolve gradually by a typically trial and error process. Hull found that the typical curve of concept formation is ogive in shape, with a short period of initial positive acceleration, and then an ultimate negative flexion.

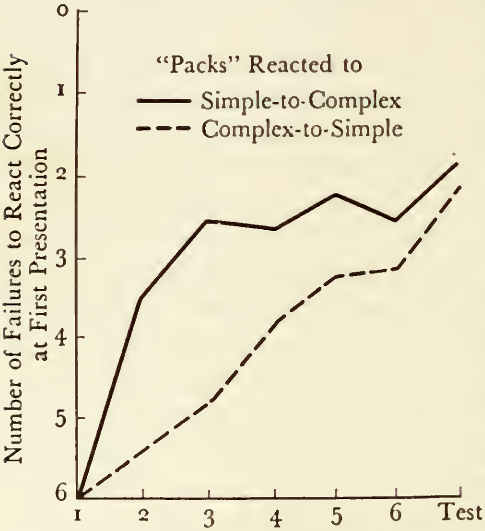


FIG. 83. Rate of concept formation by two methods

From Hull in Psychol. Monog., 1920, 28, No. 1, p. 29, Fig. 3.

Another point of attack on the process of generalization is to determine what aspects of a series of terms cause them to be related under a common classification — or identified. Is it adequate to say that there are always *identical elements* as such? What causes a series of terms to be judged similar or reacted to as similar? To test this, Yum set up the following experiment: He tested the influence of three kinds of similarity: (1) Similarity of spelling (nonsense syllables); (2) similarity of words, in meaning; and (3) similarity of visual patterns. In the first experiment the original lists learned consisted of a series of stimuli and their paired associates. The stimuli were hyphenated nonsense syllables; the response associates were words, thus: — Stimulus: R E B — Q I M; Response: Wolf. In the recall, the same stimuli were used in the control condition, but in the experimental condition they were altered by having one or more letters changed. The results show that all alterations reduced the amount recalled significantly, and in proportion to the number of letters altered. In his second experiment, Yum used lists of paired associate words. The stimulus word and its paired response word were unrelated in meaning. In recall, other words having varying degrees of similarity of meaning to the original stimulus word (as previously determined by 20 judges) were substituted for it. Thus, for the original stimulus " house," the word " cottage " was substituted in one condition, and the word " barn " in another. He found that where the same stimulus was repeated in the recall test, 50 percent was recalled; where a substitute word of the first degree similarity was used, 32 percent was recalled; and with a substitute of the second degree similarity, only 11 percent was recalled. The third experiment, using geometrical designs for stimuli, and words for responses, with substitute stimuli of four different degrees of similarity, as previously decided by judges, showed an analogous trend. The percentages recalled, with decreasing degrees of similarity, were 84, 64, 49, 45, and 36.

In these experiments, similarity is arbitrarily defined in terms of the reactions of judges. There is no necessary implication of partial identity, or any other specific kind of similarity.

The foregoing experiments in concept-formation conceive of the processes in terms of traditional psychological concepts of association and trial and error learning. Recently other points of view have been advanced, notably the point of view of Gestalt psychology, that the process involves a sudden flash of insight which is not describable in terms of previous steps. This point of view will be contrasted with the traditional functional point of view in the discussion of the processes of reasoning which follows.

REASONING

THE tendency of psychology is to deny reasoning any uniqueness as a psychological process, and to treat it as an instance of the general problem-solving process which we have already discussed, on the simpler level of perceptual motor learning.

The chief difference, as has been pointed out by Carr, is that whereas perceptual-motor problem solving involves the manipulation of environmental objects on an overt basis, with trials and errors overtly executed, reasoning, on the other hand, involves the manipulation of schematic representatives of overt movements, i.e., ideas. This implicit trial and error process is not evident to the observer and hence the process appears like a sudden flash of insight or intuition. But the intermediate steps are there. However, some important differences exist which have been brought out by experiments on reasoning.

The Problem Set or Aufgabe. — An important factor in all problem solving is the motivating condition or need. But in reasoning this motivating factor is more clearly formulated ideationally. Usually some hypothesis or goal idea is explicitly formulated. The entire process of reasoning is a conscious, intentional working toward this goal.

Foresight. — Though the solution is a trial and error process, nevertheless the selection of relevant and elimination of irrelevant ideas is facilitated by the ever present foresight of the goal. It is less " blind." It is more rapid and economical because of the substitution of schematic ideas for overt objects and movements. Thought is short-circuited behavior.

Inference. — The process of inference, or the application of general rules to the present situation, is an added advantage over perceptual-motor trial and error which seldom goes beyond the limits of the particular instance. The ability to generalize and form concepts has been shown to be a by-product of language development.

The Solution. — An important difference exists in the nature of the solution. The solution of a perceptual-motor problem is said to be a chance affair. So is that of reasoning in that the successful move was not anticipated. But the successful move may have to occur repeatedly before it becomes *established* to the exclusion of all the false moves, in the former case. In reasoning on the contrary the chance success is often clinched at once, due to the clearness of the goal idea, and no long fixation process is necessary.

Finally, reasoning is followed by generalization. The solution is not left as a particular solution of a particular problem. It may be formulated as a general conclusion which makes possible its application to a wide class of comparable situations. This again is made possible by the conceptual and schematic nature of the whole process.

OTHER POINTS OF VIEW

THE above description of the process of reasoning expresses a somewhat onesided point of view. It fails to take into account the concept of " Einsicht " developed by the Gestalt School. Our description assumes that the solution is essentially a trial and error process in which the various suggested solutions which develop in the process do so under the operation of the associational laws, as guided and directed and expedited by the ideational foresight of the goal or purpose. When the solution occurs at once we attribute it either to the limited number of relevant alternatives, under the circumstances, or to the efficient guidance of the goal idea, or to the ability to generalize from similar past situations.

The Gestalt School explain the matter differently. Köhler insists that the solution is implicit in the situation and is instantaneously imposed upon the individual. The physical Gestalt becomes a mental Gestalt. No process of association is admitted in novel situations. It is argued that the uniqueness of the situation precludes the operation of association. Köhler therefore, appeals to " Einsicht," which implies an intuitive flash, and is not to be confused with the concept " insight " or " foresight " which merely means the capacity to ideationally foresee or anticipate on the basis of past associations. The concept " Einsicht " is based on the assumption of the immediate formation of a mental configuration in response to the presentation of the problem, which has within itself a configuration.

Maier has expressed this a little more tangibly in hypothetical brain terms. The brain (central nervous system) is considered to be a region in which dynamic tensions are constantly operating to create temporary patterns or gestalts, which on the subjective side would correspond to ideational configurations. A problem would consist of any two elements in a situation which had never before been associated, i.e., isolated elements. But the very existence of the two elements in the problematical situation causes a tension to be set up amongst the brain patterns representing these two isolated terms. This tension creates a readiness or disposition for the gestalt to be completed, i.e., for the solution to occur to the individual. Many factors may aid or hinder the solution, as irrelevant thoughts, or distractions, or hints, but the essential thing is the existence of this tension. Hence, Maier would describe the essential elements of a reasoning or problem-solving process as (1) the existence of a problem-situation necessitating the bringing together of two isolated experiences, which creates (2) the stress or tension, and (3) the resulting association of the two isolated experiences.

In testing this hypothesis Maier has performed some interesting experiments, both on humans and on animals. For example, in one experiment, two cords were hung from the ceiling of a room at some distance from each other. The subject was told to tie the ends together. If he held either cord in his hand he couldn't reach the other. The only other article in the room was a pair of pliers. To solve the problem, therefore, the subject had to discover the method of tying the pliers to the end of one string, and, using this as a pendulum, to bring the other string over to it. The two isolated experiences are (1) the cord, with its various properties, length, ability to swing, etc., and (2) the pliers whose properties are, among others, weight. These are integrated in the idea of " pendulum."

Another experiment of Maier's, performed on rats, was as follows: — A rat was allowed to become familiar with a certain room. This constituted experience 1. Then, with food placed on a table, the rat was taught to run an elevated pathway to the food. This was called experience 2. Finally, the rat was placed in the familiar room, but distant from the elevated pathway, and had to go to the elevated path to obtain food, and solve the problem. His success in doing so was explained as due to the combining of the isolated experiences 1 and 2.

The concept of field of strain is justified on the ground of Child's hypothesis of metabolic gradients. For Child has found evidence that when a particular region of an organism receives extra stimulation, the rate of metabolism in that region is increased, and that region achieves dominance. Presumably a field of strain would be established between that and *neighboring* fields. This part of the concept is plausible, though highly speculative at present. Its chief difficulty is that it fails to fit easily into the established universe of discourse of psychology and hence is handicapped by an initial lack of meaning. But isn't the assumption of *isolated experiences* in a mature organism unjustified? The experiences may be isolated as far as immediate associations are concerned. But how about mediate ones? And how about the failures, when the isolated experiences remain isolated? Isn't it necessary that both the isolated experiences be aroused by the stimulating situation at the time the integration occurs? And, if so, why not classify the phenomenon as merely a new association by contiguity? Granted it is not explainable in terms of the operation of *past* associations (though they doubtless help), nevertheless it seems to obey one of the established principles for the formation of *new* associations, namely contiguity of neural excitation.

Heidbreder, as a result of observations of subjects when placed in completely novel problem situations, concludes that the solution is not effected by any special process, or series of events which may be identified as a complete act of thought. Thinking then can only be defined empirically as whatever happens when a problem is solved. However, she does find abundant evidence of trial and error, tentative acceptance and rejection of hypotheses. Since the introspections were taken while the thinking process was taking place, and before the subject knew the true answer, there was little opportunity for rationalization about the nature of the process. The problem consisted in presenting a series of cards containing geometrical figures, each accompanied by two small symbols. The subject was to handle the material in a way arbitrarily decided on by the experimenter, but was told nothing. The situation was therefore novel, but offered an opportunity to study the steps in the development of the solution, provided such steps existed.

Heidbreder finds two general methods of meeting a problem, *participant* and *spectator* behavior. The former involves taking an active hypothesis and acting on it, at least tentatively. It is the old trial and error type of response. The latter involves passive observation — the waiting attitude — until a hypothesis shall dawn. She also notes four classes of operations present — resulting in analysis, synthesis and the discarding and supplying of content. There is also noted an organization of the responses as a whole, which probably corresponds to the guidance exerted by the problem idea. One feature of the trial and error process is that the reactions following success are more likely than those following failure to represent genuine advances in thinking. As to the relative fruitfulness of spectator and participant behavior, the former is found to lead to solutions quite as often as the latter. Comparing her experimental findings with the theoretical formulation of Dewey, contained in his book, "How We Think," Heidbreder finds many discrepancies. In brief she finds no basis for Dewey's "complete act of thought," affirming that there is no discernible combination of events which is indispensable to the solution of a problem.

Kuo attempted by experiment to demonstrate the possibility of studying the so-called higher mental processes without using introspection at all. However, he employed verbal reports of the subject, and his approach is therefore introspective in the same sense that Heidbreder's study is. Kuo used lists of Chinese characters and English equivalents ostensibly presented as a memory exercise in paired associates. But five radicals occurred in the Chinese characters repeatedly: the symbols for water, female, month, hand, and metal. Hence, the subjects could learn these five and generalize from these to all the words, and thus aid their learning by partially anticipating the word's meaning. Some negative instances were introduced. After learning the characters, the subjects were tested for the meanings of the radicals, to see whether they had made the inductive inference. They were questioned as to how they discovered the generalized meaning of the radicals. Kuo concludes that five aspects are present in inductive inference: — (1) the reaction to the relationship; (2) the number of cases on the basis of which the inference rests; (3) the adequacy of the hypotheses formed; (4) the detection of negative instances; and (5) the use made of the negative instances in correcting tentative hypotheses.

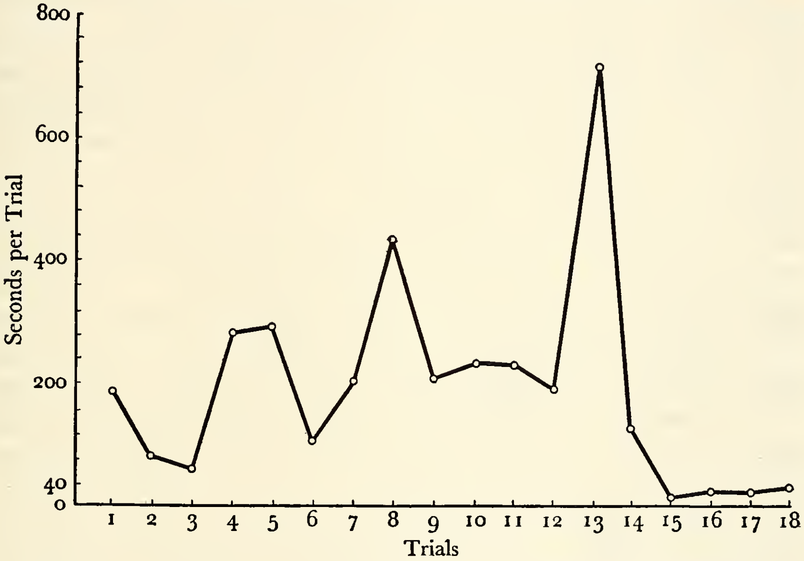


FIG. 84. Positively accelerated curve of puzzle solving

From Ruger in Archives of Psychol., 1910, 2, No. 15, p. 52, plate 2.

Peterson, in his study of the operation of the higher mental processes in rational learning, finds that the trial and error principle predominates. He utilized the same kind of bead-drawing problem which was later used by Waters in studying guidance. He detects three stages in the process: (1) the abstraction of elements from the problem situation, (2) the combination of the essential elements into higher conceptual units, and (3) the application of these higher unitary processes to situations other than those out of which they arose. The last of these steps was not necessarily present.

The trial and error nature of human reasoning was emphasized most strongly by Ruger in his early study of puzzle solving. Human and animal procedures were found to be characterized as much by their similarities as by their differences. Ruger's puzzle situations involved considerable motor manipulation to be sure, and in this respect differed from the studies of Heidbreder and Peterson. But he also emphasizes the sudden flash of insight or "seeing through the thing" which, he says, "is a very distinct experience." "In many cases it came as an extremely sudden transformation." It was given objective verification by the sudden drop in the learning curve which accompanied it. See Figure 84. Of course, the question as to whether this sudden flash was merely the culmination of a series of steps of which the subject was only dimly aware, and which paved the way for the final clicking into place of the logical elements involved, is still open. Ruger found much evidence for conscious analysis and testing of hypotheses and search for new assumptions. Perhaps the difference between his conclusions and those of Gestalt psychologists is that he admits the value of the trial and error process preceding and often leading up to the flash of 'insight'; whereas the configurationists deny its importance or relevance.

REFERENCES

Bills, A. G. The influence of muscular tension on the efficiency of mental work. *Amer. J. Psychol.,* 1927, 38, 227–251.

Buswell, G. T. An experimental study of the eye-voice span in reading. Univ. Chicago Dept. Educ., 1920, pp. 1–105.

Calkins, M. W. An introduction to psychology. N. Y. 1908, Macmillan, pp. 128–136.

Carr, H. A. Psychology: a study of mental activity. N. Y. 1925, Longmans, Green, p. 124.

Child, C. M. Physiological foundations of behavior. N. Y., 1924, Holt & Co.

Clark, R. S. An experimental study of thinking. *Arch. Psychol.,* 1922, No. 48, p. 96.

Courten, H. C. Involuntary movements of the tongue. *Yale Psychol. Studies,* 1902, 10, 93–96.

Curtis, H. S. Automatic movements of the larynx. *Amer. J. Psychol.,* 1899, 11, 237–240.

Dewey, J. How we think. Boston, 1910. Heath & Co., pp. 1–224.

Dodge, R., and Cline, T. S. The angle of velocity of eye movement. *Psychol. Rev.,* 1901, 8, 145–157.

Fisher, S. C. The process of generalizing abstraction; and its product, the general concept. *Psychol. Monog.,* 1916, 21, 1–213.

Freeman, G. L. Mental activity and the muscular processes. *Psychol. Rev.,* 1931, 38, 428–449.

Golla, F. L. The objective study of neurosis. Lancet, 1921, 201, 115, and 212.

Golla, F. L. The relation of muscular tonus and the patellar reflex to mental work. *J. Ment. Sci.,* 1929, 75.

Heidbreder, E. F. Problem solving in children and adults. *J. Gen. Psychol.,* 1928, 35, 522–545.

Hollingworth, H. L. General principles of redintegration. *J. Gen. Psychol.,* 1928, 1, 79–91.

Huey, F. B. The psychology and pedagogy of reading. N. Y.: Macmillan, 1909.

Hull, C. L. Quantitative aspects of the evolution of concepts. An experimental study. *Psychol. Monog.,* 1920, 28, 1–85.

Jacobson, E. Differential relaxation during reading and writing and other activities as tested by the knee jerk. *Amer. J. Physiol.,* 1928, 86, 675–693.

Jacobson, E. Electrical measurements of neuromuscular states during mental activities. *Amer. J. Physiol.,* 1930, 91, 567–608, also 94, 22, 34.

James, Wm. Principles of psychology. N. Y., 1890, Holt & Co. Vol. I, p. 243.

Judd, C. H., and Buswell, G. T. Silent reading: a study of various types. *Univ. of Chicago, Suppl. Ed. Monog.,* 1922, No. 23, pp. 1–160.

Judd, C. H., McAllister, and Steele. Introduction to a series of studies of eye movements, by means of kinetoscopic photographs. *Psychol. Rev. Mon. Suppl.,* 1905, 7, No. 29, 1–16.

Köhler, W. Gestalt psychology. N. Y. Liveright. 1929, pp. 1–403.

Külpe, O. Ueber die Objectivirung und Subjectivirung von Sinneseindrücken. Philosophische Studien, 1902, 19, p. 508.

Kuo, Z. Y. A behavioristic experiment on inductive inference. *J. Exper. Psychol.,* 1923, 6, 247–293.

Maier, N. R. F. Reasoning in white rats. *Comp. Psychol. Monog.,* 1929, 6, No. 29, p. 93.

Maier, N. R. F. Reasoning and learning. *Psychol. Rev.,* 1931, 38, 332–346.

Monroe, M. Methods for diagnosis and treatment of cases of reading disability. *Genet. Psychol. Monog.,* 1928, 4, 333–456.

Moore, T. V. The process of abstraction: An experimental study. *Univ. Calif. Public. in Psychol.,* Vol. I, No. 2, 1910, pp. 124.

Ogden, R. M. Imageless thot; resumé and critique. *Psychol. Bull.,* 1911, 8, 183–197.

Peterson, J. C. The higher mental processes in learning. *Psychol. Monog.,* 1920, 28, No. 129, pp. 1–121.

Pintner, R. Inner speech during silent reading. *Psychol. Rev.,* 1913, 20, 129–153.

Reed, H. B. The existence and function of inner speech in the thought processes. *J. Exper. Psychol.,* 1916, 1, 365–392.

Ruger, H. A. The psychology of efficiency. *Arch. Psychol.,* 1910, No. 15, 2, pp. 88.

Stoy, E. G. A preliminary study of ocular attitudes in thinking of spacial relations. *J. Gen. Psychol.,* 1930, 4, 379–385.

Stroud, J. B. The role of muscular tensions in stylus maze learning. *J. Exper. Psychol.,* 1931, 14, 606–631.

Terman, L. M. The measurement of intelligence. Boston, Houghton Mifflin. 1916, 1–362.

Thorsen, A. M. The relation of tongue movements to internal speech. *J. Exper. Psychol.,* 1925, 8, 1–32.

Titchener, E. B. Experimental psychology of the thought process. N. Y. Macmillan, 1909, pp. 173, 183, 187.

Washburn, M. F. Movement and mental imagery. Boston, Houghton Mifflin, 1916.

Watson, J. B. The place of kinaesthetic visceral and laryngeal organization in thinking. *Psychol. Rev.,* 1924, 31, 339–348.

White, M. M. Relation of bodily tension to electrical resistance. *Proc. Okla. Acad. Sci.,* 1929, 9.

Woodworth, R. S. A revision of imageless thought. *Psychol. Rev.,* 1915, 22, 1–27.

Wyczoikowska, A. Theoretical and experimental studies in the mechanism of speech. *Psychol. Rev.,* 1913, 20, 448–458.

Yum, K. S. An experimental test of the law of assimilation. *J. Exper. Psychol.,* 1931, 14, 68–82.

Part Five — Work and Fatigue

CHAPTER XX

ELEMENTARY RESPONSE PROCESSES — REACTION TIME AND ATTENTION

THE TOPIC of Work and Fatigue, like Learning, is a study of the total functioning organism. But, whereas Learning is concerned with the formation of habits, or reaction patterns, Work and Fatigue has to do with the operation of perfected reaction patterns or systems, and the conditions which raise or lower the individual's level of performance. The organism is viewed as a functioning machine, and its output is evaluated in terms of certain arbitrary criteria, as speed and accuracy. Like every other machine, the human organism operates in terms of certain general principles, an understanding of which is essential to the explanation of its performance in complex operations. A major part of the task of explaining the complex behavior is simply the recognition of these general principles of reaction when they are present. They will be discussed in the following pages under the topics of 1. Elementary Response Processes, 2. Reaction Time, and 3. Attention as a Motor Phenomenon.

ELEMENTARY RESPONSE PROCESSES

IT is necessary to adopt some method of analysis of complex operations into simple response units. These units are understood to be conceptual merely; selected for purposes of analysis, and probably oversimplifying the facts. But the virtue of the units lies in their simplicity and logical clearness. We might use the concept of "reflexes" as units. But the term reflex is often used in psychology to mean native reaction tendency, whereas we wish to include learned integrations. Another objection is that the psychological term is likely to be confused with the physiologist's "reflex" which has a much more restricted meaning. Hence, the concept of "stimulus-response" arc is adopted as the conceptual unit. Any complex behavior can theoretically be broken up into its stimulus-response components, and the efficiency of the process as a whole is a function of the operation of these stimulus-response components in combination.

Any stimulus-response arc consists of a sensori-neuro-motor process. We are already familiar with the nature of the sensory component. It is necessary to know certain essential facts about the motor component and the neural component.

Effectors

In dealing with the working organism we are chiefly interested in the activities of striped muscles, although the influence of smooth muscles and glands is never absent. The striped muscles control the movements of the skeletal bones to which they are attached, operating in lever fashion. For the movements of most parts of the body there are both flexor and extensor muscles, arranged antagonistically. Thus the biceps bends, the triceps extends the arm. When an impulse activates the biceps to contract, another stimulates the relaxation of the antagonistic triceps.

The striped muscle is composed of fibers or cells, each having a thickness of .1 mm. to .01. mm. and a length of 3 to 4 cm. These fibers, consisting of striated plasma, are enclosed in a thin membrane, the sarcolemma. Groups of these fibers form larger bundles, and the entire mass is enclosed in a sheath-like perimysium. When each individual fiber shortens, the entire muscle contracts with considerable force. Each fiber contracts with its maximum energy, so that the strength of contraction of the whole muscle is a function of the number of fibers stimulated to contract.

The contraction of the muscle fibers is normally caused by the nerve currents from the central nervous system, which enter the motor end plates, i.e., the non-medullated termini, of the motor axones. Muscle fibers can also be made to contract when stimulated by mechanical impact, electrical currents, and certain chemical and thermal conditions.

The simple phasic contraction of a muscle involves (a) a short latent period whose length, varying with load and the condition of the muscle, does not exceed 5 sigma, (b) the period of contraction, about 40 sigma, and (c) the period of relaxation, about 50 sigma, rapid at first, then slower. Temperature and drugs alter the duration of the contraction, as does fatigue.

What happens in the muscle fiber when it contracts is not fully known, but certain chemical and electrical changes have been found to occur. The oxygen forms CO_2, which is given off into the blood and expired by the lungs. Glycogen disappears, and lactic acid is formed. Certain other products, as acid potassium phosphate, may be created. Heat is liberated in the process.

Most contractions of muscle are not of the simple phasic type but of the compound or tetanic form. A series of nervous impulses is conducted to the muscle fiber with such rapidity (from 30 to 100 per second) that before one contraction can be recovered from, another begins, so that the muscle is held in a prolonged state of contraction or tetanus. The frequency of the impulses reaching the muscle can be detected by means of a string galvanometer.

A muscle is never fully relaxed in the normal state but is said to have a certain degree of tonus. That this is due to impulses from the motor nerves is demonstrated by the fact that a muscle from which the motor nerve is severed loses its tonus and becomes flabby. This tonus is probably maintained automatically through neural arcs whose afferent organs lie in the muscle and are stimulated when the muscle relaxes beyond a certain point. Muscular tonus functions especially in postural responses, but it is a necessary feature in all responses, as a preparatory attitude. An individual's tonus varies from time to time, and with it the efficiency of his reactions. Fatigue, for example, reduces tonus.

If repeated electrical stimulations of equal strength spaced at regular intervals are given a muscle, the resulting contractions are as follows: first, a strong contraction, then a short series of weaker ones followed by contractions of increasing strength due to the beneficial effect of the muscle's activity on itself. Ultimately the contractions grow progressively weaker until no further contraction is elicited. This break down is known as muscular fatigue.

The Connecting System

Certain facts about the functioning of nerves must be understood in studying the problems of work and fatigue. It was at one time supposed that the isolated nerve trunk was relatively unfatigueable. Experiments of the following sort tended to strengthen this notion: Bowditch (1885), after applying the drug curare to a muscle to block the passage of nerve impulses into the muscle, so that it would not be fatigued, excited the nerve several times a second, for about five hours. When, at the end of this period, the muscle recovered from the effect of the drug, the muscle responded when the nerve was excited. It is therefore assumed that the nerve had not fatigued, but was still capable of conducting with undiminished energy. Nerve fibers however were found to fatigue from continuous uninterrupted electrical stimulation. But Harvey (1912) found that a trapped wave of neural excitation set up in a ring-shaped preparation of a jelly fish could course over the circular path for as long as eleven days with no appreciable decline in rate. It is estimated that the wave must travel over 457 miles in this time, its rate being about 0.5 meters per minute.

On the other hand, all recent evidence points to the fatiguability of the nerve. For example, Tashiro demonstrated that CO_2 is given off from an excited nerve. He was able to suspend a nerve preparation in an air tight bell jar, and measure the amount of increase of CO_2 in the jar resulting from electrical stimulation of the nerve. Gerard has obtained more accurate measures of the amount of CO_2 from excited nerve. Moreover, if a nerve is deprived of oxygen, conductivity and irritability are suspended. Gerard has discovered that heat is given off from an excited nerve.

These and other facts point to the conclusion that the nerve impulse is not purely electrical, but is in part metabolic, involving chemical changes in the cell, with oxidation of tissue. The process is described as alternate waves of chemical change and electrical currents extending a very short distance along the fiber repeated throughout the length of the nerve, so that the speed of the impulse is much slower than its electrical nature would suggest, being about 100 feet per second. There is, according to Lillie, "the rapid passage of waves of chemical decomposition (probably oxidative in nature, and involving some structural change) over the surface of the reacting element, followed immediately by a reverse change which restores the original or resting condition. Associated with the chemical process is a local electric circuit by whose electrolytic action the chemical change is apparently determined."

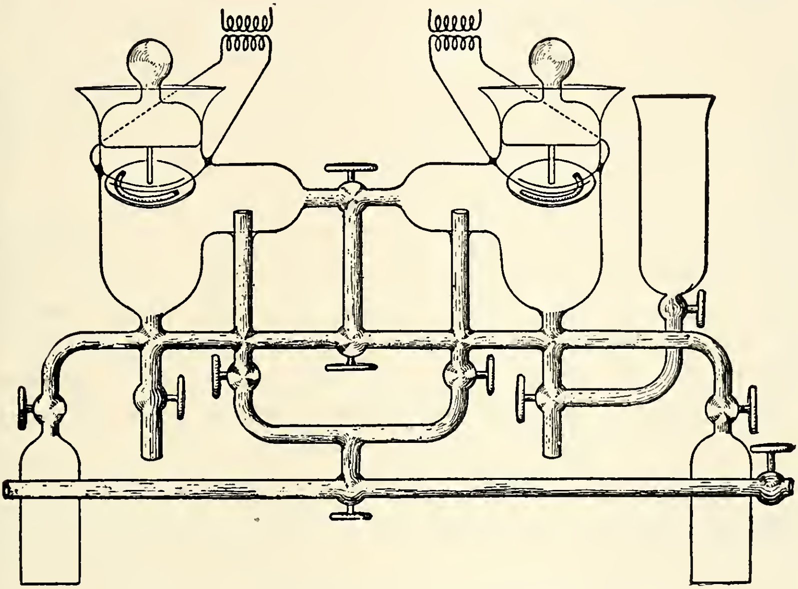


Fig. 85. Apparatus for studying CO_2, etc.

After Tashiro in *A Chemical Sign of Life,* Univ. of Chicago Press, 1917, p. 113, Fig. 3.

Another line of evidence is the changes which histological examination has uncovered in the cell body of fatigued nerves. The Nissl substance undergoes a process of coagulation and is eventually absorbed. Since this substance probably functions in nourishing the cell, its behavior points to the metabolic nature of the change which fatigue causes in the nerve.

We are compelled to assume, then, that the nerve is fatiguable. However, reduced functioning or fatigue of neural arcs is probably only in part caused by the fatigue of the nerve fibers which has been shown to be extremely slight. It is also caused by heightened synaptic resistance. The permeability of the synapses has been found to be decreased by general fatigue as by drugs, due perhaps to fatigue products from the nerve or surrounding tissues. And finally, decreased responsiveness probably develops in the motor end plates, as well as in the sensory end organs.

Refractory Phase. — Closely related to the phenomenon of fatigue in reflex arcs is that of refractory phase. Immediately after responding to a single stimulation, any excitable organ loses its excitability and becomes 'refractory' or unresponsive for a brief period. This is true of nerve as it is of muscle. The length of the period differs with the organ stimulated varying from .01 second in skeletal muscle to .002 seconds in nerve fiber. The most striking case of refraction, that of the heart, persists about 0.4 seconds. In the total reflex arc, involving several units, the refractory period is much longer, varying from a fifth second to as much as two seconds. That the refractory period is a phenomenon of the central part of the reflex arc and not due to the muscle or sense organ is proved by the fact that the same muscle shows refractory periods of different duration according to the reflex combinations into which it enters; and that a reflex aroused by stimulating one receptor is refractory to stimulations of all other receptors which are normally capable of arousing it. A closer analysis of the refractory period shows that it consists of three phases. These phases may be illustrated by the diagram in Figure 86.

Immediately after an original stimulation S_1, there will be a brief period when no response can be elicited. This is called the (1) absolute refractory phase. Then follows a period during which a weak response can be aroused. This is the (2) relative refractory phase. This is followed by a point at which a stimulus will arouse a stronger than normal response, the (3) hyper-normal phase. After this the reflex arc returns to its normal state of excitability.

Cumulative Refraction.—Recently evidence has been advanced by Field and Brücke, among others, that when a nerve is stimulated at intervals so frequent that each stimulation falls within the refractory period created by the preceding one, there will be a cumulative effect. This means that the responses will gradually become weaker until ultimately no response can be elicited. This would be the point of absolute breakdown of the arc.

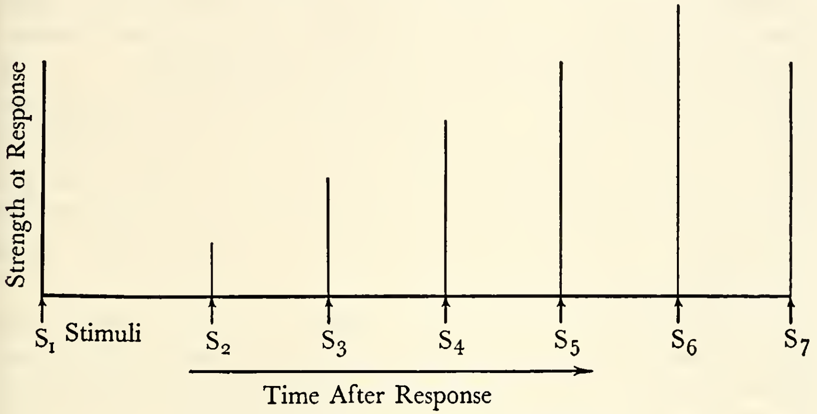


Fig. 86. The refractory period

Principles of Reflex Integration

There are certain facts about the behavior of reflex arcs in combination which throw light on the problems of work and fatigue. Among these are the principles of facilitation and inhibition.

Facilitation and Inhibition.—The concept of the isolated reflex arc is a convenient abstraction. But such isolation never occurs actually. Any given reflex arc is a part of a very complex system, and its action is a function of every thing going on in the nervous system at the time. If these accompanying conditions reinforce the reflex, it is called facilitation; if they weaken or prevent its occurrence, it is called inhibition.

Final Common Path. — It is quite a common thing for impulses from two or more afferent pathways to converge upon a single efferent pathway. The result is a reinforced response. When one sensory stimulation is not of itself strong enough to elicit a response, several stimulations may converge upon a final common path and break through the motor threshold. This is known as *convergence* or *summation of stimuli.* Another kind of summation effect is that in which several successive weak stimulations to the same sense organ will have a summative effect in that sensory motor arc and will thereby break through the threshold.

Spread of Excitation. — This refers to the fact that the excitation of one afferent pathway may arouse several efferent paths causing the motor response of several muscles. This, like the phenomenon of final common path, is made possible through the existence of centers and the convergence of paths upon them.

Allied and Antagonistic Arcs. — Two or more arcs may be so related that they arouse motor responses which are in harmony. Such is the case in the scratch reflex of the dog as demonstrated by Sherrington. If a stimulation of a point on the dog's shoulder sets off the scratch reflex, then the simultaneous stimulation of a neighboring point will reinforce the reflex. Or, in the human knee jerk, if the fist is clenched hard just at the moment the patellar blow is delivered, the strength of the jerk will be enhanced. This facilitation may give way, thereafter, to inhibition, after about half a second. The following of the facilitative by the inhibitive phase is called the diphasic law.

On the other hand many arcs function antagonistically to one another. When this is the case, one arc interrupts the functioning of the other. In the case of the scratch reflex, if the right foot is excited while the left is reacting, the scratching movement is inhibited. One stimulus gains the right of way while the other is excluded. If the stimuli are timed right, and evenly balanced in strength, they may mutually inhibit one another. Much depends on the relative timing of the two stimuli. For example, in the case of the knee jerk it was found by Bowditch and Warren that a reinforcing stimulation, like a sudden squeeze on a dynamometer, if introduced about a half second before the blow on the knee, would inhibit the knee jerk.

Theories of Inhibition.—Historically, the first theory was that of a particular region or center in the brain which, when activated, exerted an inhibitive effect on reflexes. The theory was advanced by Setschenow, about 1863, and is known as the *"Center" theory of inhibition.* It arose from the discovery that stimulation of the centers in the optic thalamus, corpora quadrigemina, and medulla oblongata tended to depress reflex excitability. But Schiff and Herzen demonstrated that strong irritation of *any* part of the nervous system, peripheral or central, was accompanied by a depression of reflex activity.

A second theory, that of *interference,* was advanced by Goltz about 1869, as a result of studies of the spinal frog. This assumes that any reflex center which is functioning forfeits its functional activity for that particular reflex, if it receives any other afferent impulse. But the objection is that any physical interference would result in the mutual blocking of both impulses, rather than the complete suppression of one, and complete expression of the other.

A third, or metabolic, theory was advanced by Hering, 1878, in connection with his explanation of color vision in terms of antagonistic processes of anabolism and katabolism. The theory was widened to include inhibition in all neuromuscular action; inhibition being identified with the assimilative phase, and excitation with the dissimilative phase. Verworn objected to the theory on the basis of his experimental results which pointed to inhibition as due to "dissimilatory depression."

The two theories which have monopolized recent attention are (1) the *refractory phase* theory of Verworn, and (2) the *drainage* theory of McDougall. The former theory was adopted by Lucas and by Forbes. Among psychologists, Dodge has been its chief advocate. The theory assumes that decrements developing in reflex arcs are due to the decreased excitability of the arc resulting from previous stimulation. Fatigue is assumed to be an inhibition phenomenon in which the repeated stimulation of a given arc has resulted in cumulative refraction, thereby causing a gradual weakening of the response. Whether all forms of inhibition can be explained in the same way is questionable. Dodge has demonstrated that an initial sub-threshold stimulation can establish a refractory phase in any arc so that a series of strong stimulations following will not arouse a response. This is true even when the initial stimulation is so weak as not to be responded to overtly. Sherrington has pointed out that "the inhibitory process does not amount merely to the subsidence of an excited state in its own nerve; it is more than that, for it is able to suppress excitation processes started from other sources." On this basis the refractory phase principle might be broadened to include such cases as the inhibition of the knee jerk by the simultaneous excitation of other arcs, and the cases of general central inhibition involved in sleep, etc., which attracted Pavlov's interest.

The latter theory, that of "drainage," was developed chiefly by McDougall who assumed that inhibition is due to the draining off of the excitatory impulse from the arc in some way. On the analogy of the flow of liquid through pipes, he argues that the neural energy available in a given arc (a) will be drained into any strongly stimulated arc (b) which is associated with it by collateral neurones. This results in the inhibition of the motor process connected with the functioning of arc (a). The chief objections to the theory have been pointed out by Dodge. He argues that the assumption of "neurin" or nervous energy which can be distributed into various channels is contrary to the known facts about the electrochemical nature of the nerve impulse. It also violates the "all or none" law, which holds that a nerve always responds with its maximum energy, if at all.

A final theory, the chemical theory discussed by Adrian and others, which assumes that there is produced at some point in the reflex arc an inhibitory substance capable of neutralizing the excitatory substance produced when an impulse passes over the arc, is designed to explain reciprocal innervation. Sherrington used the term reciprocal innervation to describe the fact that when one of a pair of balanced muscles like the biceps and triceps is excited, the other must be inhibited or relaxed simultaneously; otherwise its tonus would check the effectiveness of the other's contraction. Hence it is necessary to assume that an excitatory impulse may be turned into an inhibitory impulse somewhere in the arc. The chemical theory, however, might be stretched to include all cases of inhibition.*

In concluding the topic of inhibition, it should be emphasized that there are many forms of inhibition, perhaps all different; that there is yet no one explanation for them; and that perhaps they will ultimately be found to require more than one theoretical explanation. Nevertheless, the *phenomena* of inhibition and facilitation, in the broadest sense, form the central topic of work and fatigue.

Reaction Time

Closely related to the concept of the simple stimulus response arc is that of the simple reaction which hypothetically involves a unitary system consisting of a sense organ with its afferent, central, and efferent neural connections and the muscle. However, no psychologist would be guilty of assuming that the simple reaction, as studied in the laboratory, involves any such limited system. Historically the study of reaction time in the simple reaction grew out of the discovery that measurements in science in which human observation is a factor were affected by what was called the "personal equation." † The question was raised as to the time element involved in the human reaction to a stimulus. The problem became one of determining the exact time elapsing between the instant at which the stimulus is presented and the instant when the response is made. The hope of determining in this way the approximate speed of neural impulses in arcs was probably misplaced, because several factors are present in the total reaction time beside the neural factor. There is the inertia of the sense organ, the inertia of the muscle and the central delay to be considered. As a matter of fact, the speed of nerve impulses in isolated neural fibers has been determined by physiologists. For example, in the nerve of the frog it is about 28 meters per second. In human nerve fibers the average speed is estimated to be about 120 meters per second. Obviously, this rate as compared with the rate of the simple reaction, which is around 1/5 of a second, shows that most of the delay of the simple reaction time is at the center.

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* A review of these phenomena is given in F. Fearing's Reflex action; a study in the history of physiological psychology. Baltimore, Williams & Wilkins, 1930, pp. 350.

† The history of the subject has been completely reviewed by E. C. Sanford, *Amer. J. Psychol.,* 1888 2, 3–38.

Forms of Stimulus. — Reaction times have been studied in connection with the following varieties of stimulus:

a. Stimuli of different sensory modality, visual, auditory, tactual, etc. The reaction time has been found to vary considerably with the sense organ. The following chart gives a list of reaction times for the different modalities.

REACTION TIMES FOR DIFFERENT MODALITIES

Vision	*Audition*	*Touch*	*Warm*	*Cold*	*Pain*
150–225 sigma	120–182 sigma	117–182 sigma	180 sig	150 sig	400 sig

b. Variations in the intensity of the stimulus as well as size, color, pitch, number, and complexity of stimulus. Reaction times are shorter to strong than to weak stimuli. Within the visual field green gives a shorter reaction time than red, for example.

Forms of Reaction. — Reaction times vary in terms of the particular part of the body used in responding. Times have been recorded for reactions of the hand, arm, foot, lips, and voice. The most common type is the finger reaction — pressing an electrical contact key. The fastest reaction is the squeezing of a bulb held in the hand. For vocal responses a special apparatus must be used, either the voice key or the lip key. The voice key consists of a thin metal disc like a telephone disc which vibrates to the sound waves from the voice and completes an electric circuit. The lip key reacts to the movements of the lips in speaking.

Types of Reaction Time Studied. — Studies of reaction time may be classified in accordance with the degree of complexity of the reaction into simple reactions, choice and discriminatory reactions, and associative and cognitive reactions.

Simple Reactions. — The discovery was made in Wundt's laboratory by L. Lange that a subject's reaction time varies depending on whether his attention is directed to the stimulus or to the movements involved in making the response. For this reason, the three forms of simple reaction have been distinguished.

1. The sensorial type in which the subject's attention is directed to the stimulus by the experimenter's instructions.
2. The muscular reaction in which the subject's attention is directed to preparation to respond.
3. The so-called 'natural reaction' in which the subject is left free to attend to either or both features in accordance with his own inclinations. Angell investigated the influence of practice upon this difference in time between muscular and sensorial reactions and discovered that while subjects differ in the natural type, some being naturally sensorial and others naturally motor reactors, practice can equalize the reaction times under the two sets.

Discriminatory and Choice Reactions. — Whereas a simple reaction consists of a single constant response to a single constant stimulus, a discriminatory reaction assumes a variation in the stimulus. For example, instead of instructing the subject to react when he sees a red light, he would be told that the stimulus might be either red or green, and that he should react only if it is red. The choice reaction on the other hand involves complexity on the response side. For example, the subject is instructed to react with his right hand if the stimulus is red and to react with his left hand if it is green. These reaction times are considerably longer on the average than the simple reaction times. The difference varies with the complexity. The so-called naming and reading reactions such as we have in the color naming test and in tests of reading speed may be classed as discriminatory reactions of a continuous nature, since it is necessary for the subject to discriminate between several possible stimuli when he makes a naming reaction to the specific stimulus.

Associative and Cognitive Reactions. — The 'associative' reaction may be considered a special type of discriminatory reaction. It takes several forms depending upon whether the association is 'free' or 'controlled.' For example, the subject may be instructed to respond with the first word that occurs to him when a particular stimulus word is presented. This is a free association. Or he may be asked to give an opposite to the stimulus word, or a synonym. This latter is controlled association. In general association times are longer than simple or choice reaction times, but they vary considerably, ranging anywhere from one fourth of a second to several seconds. This subject has been discussed in connection with the topic of association. Cognitive reactions are those in which a judgment is delivered or a solution given to a problematic question. They form the basis of the intelligence test questions. For example, the true-false test is a cognitive test.

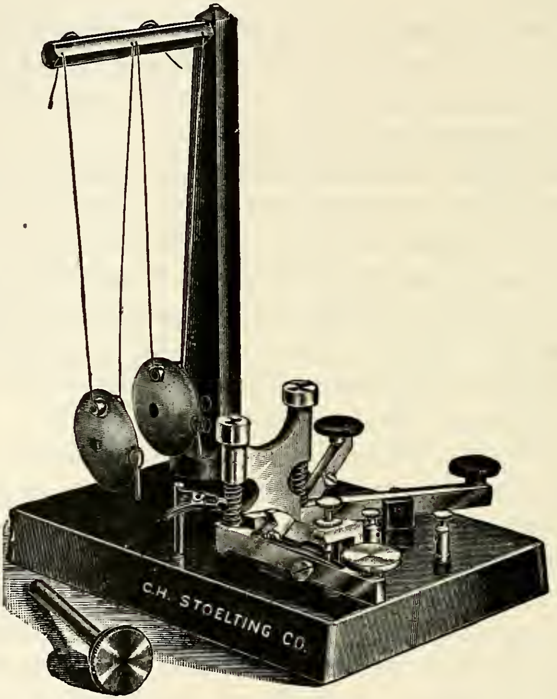

FIG. 87. Sanford vernier chronoscope

Courtesy C. H. Stoelting Co.

Reaction Time Apparatus.—All devices for measuring reaction time involve common principles. It is necessary to have (1) a constant speed control; (2) a calibrated scale of times; and (3) an instantaneous stopping and starting control. The simplest reaction time apparatus embodying these principles is the Sanford Vernier chronoscope. This employs an analogous principle to that of the Vernier calipers, used in linear measurements. A constant time control is furnished by utilizing the pendulum principle of simple harmonic motion. Since the time per swing is proportional to the length of the suspension string, it is possible to vary the time per swing at will by lengthening or shortening the string. The instrument consists of two pendulums each capable of being released instantaneously by a key control. One of these pendulums is adjusted to swing 75 swings per minute, i.e., 40/50 of a second per swing; the other swings 77 times per minute, i.e., 39/50 of a second per swing. Since each swing of the shorter one takes 1/50 of a second less time than a swing of the longer, the two pendulums if released simultaneously should again beat in unison at the 39th beat. Now if the shorter pendulum is released a very short time after the longer one, say 7/50 of a second, it will catch up with the longer one at the rate of 1/50 (i.e., 40/50—39/50) seconds per swing. Hence on the seventh swing the two pendulums will synchronize.

Now if the experimenter releases the longer pendulum at the exact instant he gives the stimulus, and the subject releases the shorter pendulum at the exact instant he reacts, the number of swings before the two pendulums again synchronize gives the reaction time in fiftieths of a second. Usually reaction times are given in 'sigma' or one-thousandths of a second, hence to convert fiftieths of a second into one-thousandths of a second we multiply the number of swings by twenty.

The two most widely used chronoscopes are the Hipp and Dunlap. These are accurate to a thousandth of a second, and allow for electrical control in starting and stopping. The Hipp chronoscope controls time by means of a vibrating reed. The Dunlap uses a vibrating tuning fork if operated

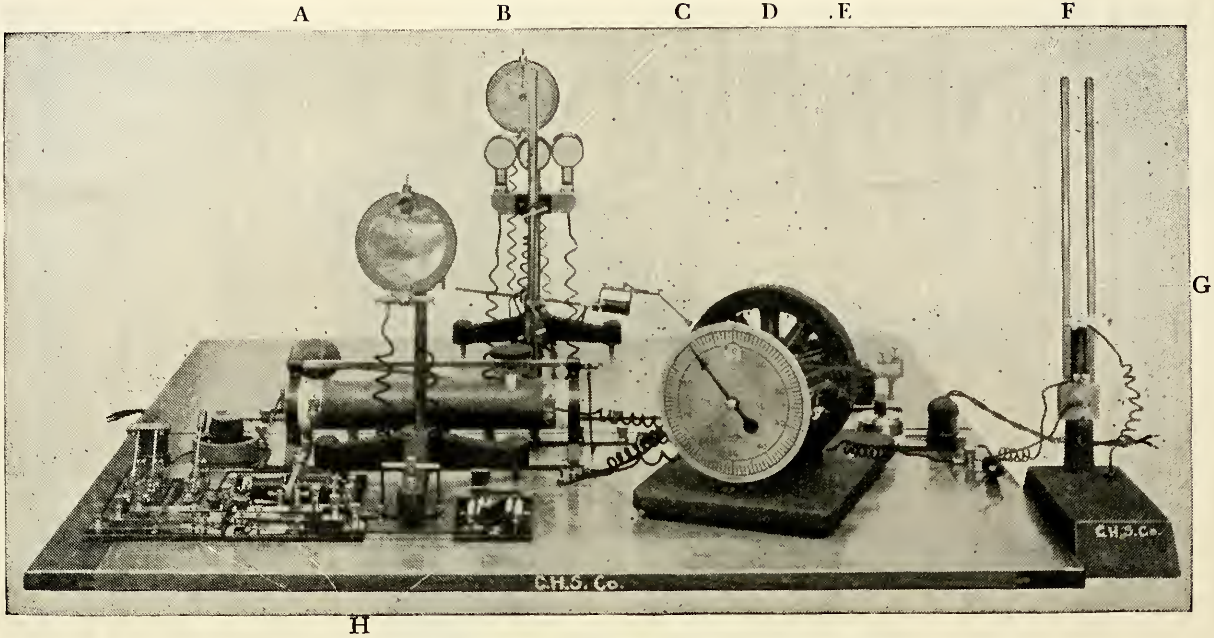

Fig. 88. Dunlap chronoscope. Chicago model

Courtesy C. H. Stoelting Co.

A — manual reaction key
B — voice keys for stimulus and response
C — visual stimulus lights
D — tactual stimulus
E — chronoscope with motor and dial graduated in sigma
F — auditory " click " stimulus
G — tuning fork governor
H — switches and keys operated by experimenter

on direct current; but if a sixty cycle alternating current is used, no fork is necessary. Reaction times can be read from a visible dial in sigma. A picture of the Dunlap chronoscope is given in Figure 88.

Factors Influencing Reaction Time

Typical times for the different types of reaction have been given. There are certain general factors which influence the length of reactions. Among the more important are practice, which shortens the time; fatigue, which lengthens it; and the time elapsing between ready signal and stimulus. Figure 89 taken from Woodrow's data on the ready signal shows the relationship between the length of time between ready signal and stimulus and the resulting reaction times.

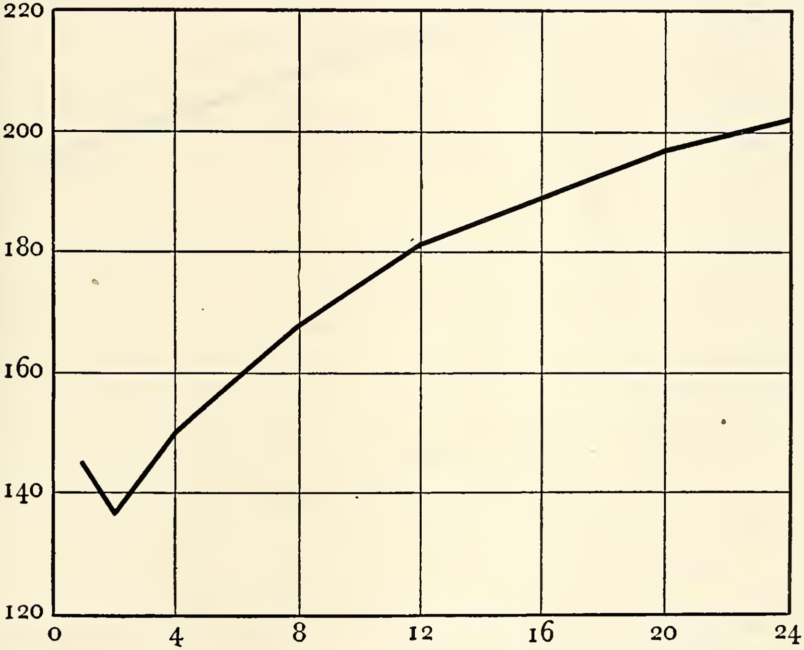

FIG. 89. Relation between ready signal and reaction time

After Woodrow in Psychol. Monog., 1914, 17, No. 5, p. 26, Fig. 3.

Recently Telford demonstrated the relationship between reaction time in successive simple and associative reactions and the length of the interval between stimuli. The stimuli were given successively at intervals varying from one-half second to four seconds. The stimulus was an auditory click and the response was made with a telegraph key. The results are shown in Figure 90. The most favorable interval is one second and any shorter interval gives a greatly prolonged reaction time. This is interpreted by Telford to mean that there is a refractory period in voluntary responses just as there is in reflexes, and that this refractory period has a duration of about one second.

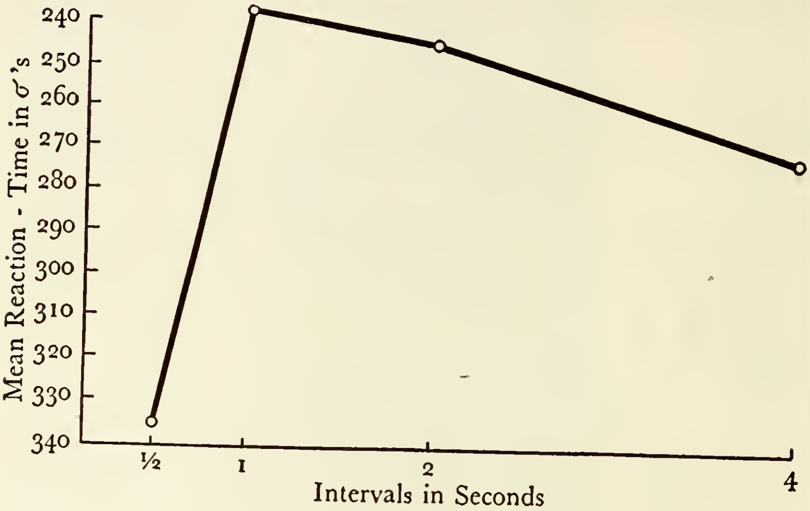

FIG. 90. Effect of frequency of stimulation on reaction time

After Telford in J. Exper. Psychol., 1931, 14, p. 10, Fig. 9.

Individuals have been found to differ widely from one another in reaction time. The question as to whether there is any general reaction time factor has been raised. If an individual is quick in one reaction is he relatively quick in all kinds of reactions? So far, the results have tended to refute the theory of a generalized reaction time.

ATTENTION AS A MOTOR PHENOMENON

IN order to understand the operation of stimulus response arcs in complex reactions it is necessary to consider attention as a motor phenomenon. We have pointed out the manner in which reflex arcs facilitate or inhibit one another in the process of integration of responses. No stimulus response arc can be considered as an isolated unit acting independently of the rest of the nervous system. Simultaneous stimulations of other neural patterns influence it. Previous reactions exert their effect. Various internal stimuli acting upon the organism, such as proprioceptive stimuli from motor attitudes, or the cortical correlates of ideational systems, affect the operation of the stimulus response arc in question by facilitating or inhibiting it. These attitudes are described collectively under the term "attention." Attention has been historically defined merely as a state of increased clearness of consciousness because of the identification of the term attention with the conscious effect rather than with the process which produces that effect. An adequate attack upon the problems of attention has thereby been delayed and the concept has lost caste. Many psychologists have come to consider attention a meaningless category on this account. One of the first to rebel against the identification of attention with its conscious effects was Ribot. He argued that attention should be identified with the motor adjustments attendant upon the process of perceiving. He was criticized with some justification for an exclusive identification of attention with the muscular processes because many of these might be mere over-flow phenomena and not essential elements of the process. Still another description of attention has been given in neurological terms. Attention is assumed to be a complex process involving the facilitation of impulses arising from particular stimuli and inhibition of all antagonistic or rival impulses. Still another view of attention has arisen out of the work on reaction time. It emphasizes the preparation for response in terms of a heightened tonicity of the reaction systems. For example, if in the simple reaction the individual attends to the performance of the response, there is a manifest increase in the tension of the muscle involved in the response as well as of the entire body.

Without question there is truth in all of these positions. We may divide attention into the following factors.

Sensory Adjustment. The sense organ or organs involved in the reception of the important stimulus are adjusted for better reception. Some of these adjustments are obvious, such as turning the eye in the proper direction; others are hidden and poorly understood as yet, such as the adjustments of the ear causing a lowered threshold for hearing certain sounds.

Motor Adjustment. It consists of a heightened tonicity of the reactive mechanisms for facilitating their action. This probably involves the principle of reciprocal innervation in the muscles immediately concerned, and it certainly involves inhibition of reaction systems already in operation which are antagonistic to the particular response. This is evident in the general inhibition of on-going activities preceding close attention. In addition, there is a widespread contraction of skeletal muscles. The experimental work proving this was described in detail in Chapter XIX under the title " Bodily Attitudes " and will not be repeated here.

Metabolic Adjustment. Attention involves marked changes in breathing, heart rate, and vascular processes. These changes have been discussed in Chapter XXIII under the title " Physiological effects of mental work."

Central Adjustment. The ancient concept of apperception draws attention to a sort of central preparation causing a facilitation of associations in the direction of the material attended to, and an inhibition of contrary or interfering associations. There seems to be an increased readiness of arousal for associations within a given sphere. This is well brought out in the case of the so-called " Aufgabe " or task idea. Not only are relevant stimuli in the environment more likely to arouse interest but also relevant ideas occur more readily. All three of these directions of adjustment can be described in terms of the mechanisms of neural facilitation and inhibition already described.

Distraction. A corollary of the concept of attention is that of distraction. Any stimulus, external or internal, which is antagonistic to the stimulus attended to, and breaks through the general inhibitory set, constitutes a distractor and the condition is called distraction. If more than one process is attended to simultaneously the two processes act as mutual distractions. However, it has been experimentally demonstrated that not all irrelevant stimuli have a distractive effect. Indeed, if the reaction systems aroused by them are not actually antagonistic to the system in operation the effect may be facilitation rather than distraction. Distraction is thus seen to be one of the particular manifestations of inhibition, and is definable in terms of its effect rather than in terms of the specific process involved. For in the case of carrying on two simultaneous processes, any stimulus which acted as a facilitator on one would act as a distractor on the other. It is one of the principles of integration that antagonistic systems tend as a result of practice to be integrated into higher order systems which are not antagonistic. For this reason, distractions tend with practice to disappear, and reaction systems which were antagonistic tend to become unified into a single pattern. A good illustration of this is found in experiments of the sort carried on by Culler on card sorting in which opposing systems of sorting which were originally highly distractive were reduced by practice to a higher order unit in which there was no longer any mutual inhibition.

Levels of action. There is a principle of neural organization which makes possible the simultaneous performance of incompatible reactions. This is the principle of levels. Action systems which belong to different levels may take place simultaneously without antagonism. Actions which have been reduced to automaticity through habit operate independently of attentive reactions taking place at higher levels. In fact a high degree of attention to irrelevant matters seems to facilitate the operation of automatic habits. For example, in an experiment of Robinson and Bills in which the subjects were required to write letter sequences continuously until the writing became automatic, the subjects reported that their performance was improved when they deliberately attended to irrelevant stimuli, such as reverie or the conversation of a friend.

Experiments in Attention

Historically, the experimental studies of attention have centered about the following topics: fluctuations of attention; the scope and range of attention; the prior entry law; and the measurement of attention.

Most of the work on fluctuations of attention is invalidated because of the erroneous assumption that the fluctuations which take place in the perceptibility of minimal sensory stimuli are identical with fluctuations in attention. But that the two are distinct is shown by the fact that the periodicities of fluctuation in clearness of minimal sensory stimulations are different for every sense organ and hence cannot be attributed to any common central factor. They are accounted for by various peripheral factors peculiar to the sense organ involved. Guilford in a recent investigation of the phenomena (1927) concluded that they were due to a number of physiological conditions, among which are, in the case of vision, local retinal adaptation, eye movements, and local central fatigue or inhibition. The true attention waves were shown by Billings to be much more frequent. He obtained them by having the subject attend continuously to a single supraliminal stimulus—a dot on a paper, the noise of a buzzer, etc. He found that subjects could not fixate a single homogeneous stimulus longer than from one to three seconds. Complex stimuli gave longer attention periods.

The experiments on range and scope of attention grew out of the question, How many things can be attended to simultaneously? But a more fruitful question is, What factors affect the span of attention? It was found that, with very short exposure time, only about five separate items could be apprehended, but that if the items were arranged in accordance with some pattern, or if they were combined into a meaningful whole, the number was very much greater. An illustration is the apprehension of words and sentences as compared with isolated letters. When it is necessary to use such short exposure times as 1/5 second, a special exposure device is used, known as a tachistoscope, one type of which is shown in the photograph.

The Prior Entry Law, emphasized by Wundt, states that, of two stimuli simultaneously given, the one toward which attention is directed will be perceived first. It has been studied by means of the 'complications clock,' an apparatus consisting of an index hand, which is watched by the subject as it repeatedly revolves with uniform speed before a clock face. At some point in the revolution, the experimenter gives the subject some other stimulation — i.e., an auditory click, or electric shock — and the subject is asked to state the position of the index hand when the stimulus was given. The amount and direction of error is interpreted as a measure of the influence of the attentive factor.

Attempts to measure the degree of attention have followed four lines: (1) direct introspective analysis of the clearness of consciousness; (2) the efficiency of performance of some task requiring attention, as the cancellation test; (3) measurement of physiological concomitants of attention, as pulse, breathing and blood volume; and finally (4) the determination of how strong a distractor or 'detractor' is necessary to counteract or overcome the attention. On theoretical grounds the last method, devised by Woodrow, is the most exact; but for the practical study of mental work and efficiency, the second method is best. Introspective reports are hardly quantitative enough, and physiological measures are too variable.

REFERENCES

Adrian, E. D. Some recent work on inhibition. Brain, 1924, 47, 399–416.

Angell, J. R., and Moore, A. W. Reaction-time; a study in attention and habit. *Psychol. Rev.*, 1896, 3, 245–258.

Billings, M. L. The duration of attention. *Psychol. Rev.*, 1914, 21, 21–135.

Bowditch, H. P. Note on the nature of nerve force. *J. Physiol.*, 1885, 6, 133.

Bowditch, H. P., and Warren, J. W. The knee-jerk and its physiological modifications. *J. Physiol.*, 1890, 11, 25–64.

Cason, H. The conditioned eyelid reaction. *J. Exper. Psychol.*, 1922, 5, 153–196.

Cattell, J. M., and Dolley, C. S. On reaction times and the velocity of the nerve impulse. *Psychol. Rev.*, 1894, 1, 159–168.

Culler, A. J. Interference and adaptability. An experimental study of their relation with special reference to individual differences. *Arch. Psychol.*, 1912, No. 24, pp. 80.

Dodge, R. A systematic exploration of a normal knee-jerk. *Zsch. f. allg. Physiol.*, 1910, 12, 1–58.

Dodge, R. Theories of inhibition. *Psychol. Rev.*, 1926, 33, 106–122; 167–187.

Dunlap, K. The Johns Hopkins Chronoscope. *J. Exper. Psychol.*, 1917, 2, 249–52.

Field, H., and Brücke, E. T. Ueber die Dauer des Refraktärstadiums des Nerven bei Ermüdung und Erholung. *Pflug. Arch. f. d. ges. Physiol.*, 1926, 214, 103–111.

Geissler, L. R. The measurement of attention. *Amer. J. Psychol.*, 1909, 20, 473–529.

Gerard, R. W. Studies on nerve metabolism. I. The influence of oxygen lack on heat production and action current. *J. Physiol.*, 1927, 63, 280–298.

Goltz, F. Beiträge zur Lehre von den Functionen der Nervencentren des Frosches. Berlin, 1869, pp. 41 ff.

Guilford, J. P. Fluctuations of attention with weak visual stimuli. *Amer. J. Psychol.*, 1927, 38, 534–583.

Harvey, E. N. The question of nerve fatigue. *Carnegie Instit. Yearbook*, 1911, No. 10, pp. 130–131.

Hering, E. Zur Lehre vom Lichtsinne. Wien, Carl Gerolds Sohn, pp. 141.

Herzen, A. Expériences sur les centres moderateurs de l'action réflexe. Turin, 1864.

Hipp, M. For description of apparatus, see Wundt, W. Physiological Psychology, 1903, pp. 387 ff.

Lange, L. Neue Experimente über den Vorgang der einfachen Reaction auf Sinneseindrücke. *Philosoph. Studien*, 1888, 4, 479.

Lillie, R. S. The nature of protoplasmic and nervous transmission. *J. Phys. Chem.*, 1920, 24, 165–191.

McDougall, W. The nature of inhibitory processes within the nervous system. Brain, 1903, 26, 153–191.

Pavlow, I. P. Conditioned reflexes: an investigation of the physiological activity of the cerebral cortex. London: Oxford Univ. Press, 1927.

Pillsbury, W. B. Attention. London, Sonnenschein, 1908, pp. 346.

Ribot, Th. A. The psychology of attention. Chicago. Open Court Pub. Co., 1890, pp. 121.

Robinson, E. S., and Bills, A. G. Two factors in the work decrement. *J. Exper. Psychol.*, 1926, 9, 415–443.

Sanford, E. C. The vernier chronoscope. *Amer. J. Psychol.*, 1897–1898, 9, 191.

Setschenow, J. Physiol. Stud. über die Hemmungsmechanism, Berlin, 1863.

Sherrington, C. S. Integrative action of the nervous system. N. Y.: Scribner, 1906, pp. 114–234.

Tashiro, S. Carbon dioxide production from nerve fibres when resting and when stimulated; a contribution to the chemical basis of irritability. *Amer. J. Physiol.*, 1913, 32, 107–145.

Telford, C. W. The refractory phase of voluntary and associative responses. *J. Exper. Psychol.*, 1931, 14, 1–36.

Twitmeyer, E. B. A study of the knee-jerk. 1902, Univ. of Penn., Phila.

Verworn, M. Irritability. *Yale Univ. Press,* New Haven, 1910.

Woodrow, H. The measurement of attention. *Psychol. Rev. Monog.*, 1914, 7, No. 76, pp. 158.

CHAPTER XXI

METHODS OF STUDYING WORK AND FATIGUE

NOW THAT we have considered the various elementary processes involved in psychological reactions, we are ready to study the operation of these factors in their complex form — the organism at work. Whereas, Learning is a study of the formation of habits, Work and Fatigue is a study of the operation of habits which have, at least theoretically, been already perfected. It is a study of the operation of perfected habits. It is concerned with the variations which occur in levels of performance as a result of continuous work.

MENTAL AND PHYSICAL WORK DIFFERENTIATED

WHAT is work? A distinction is commonly drawn between mental and muscular or physical work. However, an examination of attempted definitions will show that no such clear cut distinction is possible. For example, no one would naïvely attempt to distinguish between work of the body and work of the mind as distinct metaphysical entities or forms of energy, but many psychologists have attempted distinctions on the basis of the part or aspect of the organism involved. Thorndike defines mental work as work of the connecting system as opposed to muscular work involving muscles and sense organs. But obviously, this is an abstraction, for no task is exclusively confined to the connecting system, and neither is any task exclusively muscular. Even shovelling coal involves the use of complete neuro-muscular arcs. Watson distinguished between work of the gross and work of the finer skeletal muscles. Thinking or mental work he assumed to be differentiated from physical work in that it utilized the finer vocal muscles. This is in accordance with his theory of thinking as action of language mechanisms. But disregarding the fact that the distinction is based on a purely theoretical assumption as to the nature of thought, even so there are scarcely any mental tasks which exclude gross muscular work. For example, typing or writing articles. The most satisfactory answer is that the distinction between physical work and mental is purely one of degree; the former involving relatively more use of gross muscles and the latter involving relatively more use of the nervous system.

Work may be defined physiologically as consumption of energy. Rate of work is computed in terms of rate of energy consumption. It is fairly easy to give an equation for physical work on an analogy with the equation for physical energy. The equation is $\frac{1}{2}M \mathrm{x} V^2$ where M equals the mass moved and V is equal to distance traversed divided by time consumed. For example, the work of the organism in lifting a weight can be computed in terms of the mass lifted, the distance through which it was lifted, and the time taken. It is not certain that the result would agree perfectly with this, but the relationship is close enough. In the case of mental work on the other hand, the application of the formula is more difficult. For example, corresponding to mass in physical work we have no correlative term unless it be difficulty of the mental task, but difficulty is not a quantitative concept. How can we define difficulty? We might define it in terms of the time taken for the task or the accuracy of performance, but these are all themselves terms in the formula and consequently this amounts to defining difficulty in terms of itself. We might define difficulty in terms of subjective estimate, but subjective feelings have a low agreement with objective energy consumption. Time is easily standardized and distance has its correlate in amount of time. So that we might give the following formula for mental work:

$$\text{Work} = \frac{\text{Difficulty} \times \text{Amount}}{\text{Time}}$$

Woodworth has suggested that difficulty may be broken up into two factors which must be measured separately: (1) the nature of the task, and (2) the standard of excellence reached as measured by accuracy or some other criterion. The former he calls difficulty and the latter excellence. He thus has four variables, quantity, difficulty, excellence of result, and time; and he suggests that the only practical way to compare individuals in performance is to standardize three of the four, leaving only the fourth for measurement and comparison. This gives rise to four methods of measuring performance.

Methods of Measuring Performance

Time Measuring Methods.—Here difficulty is standardized by using materials of a uniform character. Excellence is standardized by acquiring a certain unitary accuracy or quality. Quantity would likewise be standardized.

Quantity Measuring Methods.—A fixed time is allowed in which the subject does as much as possible, maintaining a uniform quality or accuracy and using a task of uniform difficulty.

Excellence Measuring Methods.—The systematic valuation of excellence is more difficult, but at least accuracy can be unified in some such terms as number of errors, and other forms of excellence can be unified by preparing some sort of scale like the Thorndike hand writing scale, and judging the results on the basis of such a scale.

Difficulty Measuring Methods.—As indicated, this criterion offers the greatest difficulty of quantification. It is necessary to prepare a scale of tasks of varying difficulty. In some fields this is relatively easy as, for example, in the measurement of intelligence, the Binet-Simon scales represent such a set of tasks graded in relative difficulty. But in mental tasks where there is not the possibility of standardizing difficulty with reference to each group or where there is no basis for any judgment as to the relative capacity of the subjects some other criterion must be used.

Thorndike selected mental multiplication of four place numbers as the most difficult possible mental test and, on the basis of this, Arai came to the conclusion that, since she could multiply four place by four place numbers continuously for eleven hours without breakdown, mental fatigue was non-existent. But Thorndike has no evidence that multiplication of four place by four place numbers is any more difficult than any other mental operation. In fact if this task does not suffer fatigue, whereas some other task does, that is a legitimate reason for assuming that multiplication of numbers in the head is a relatively simple task.

Suppose he should use as a criterion of difficulty the percentage of persons who can perform the task successfully, as compared with the percentage who can do some other task such as multiplication of two place numbers in the head, or multiplication of numbers *on paper* correctly. Or suppose the criterion chosen was the relative number of mistakes made in the two tasks. Is this a proof that, for any given individual, the one task is more difficult than the other? No, it is simply a case of identifying difficulty with some other variable, as excellence. The same would be true if one should attempt to measure difficulty in terms of the time necessary to complete the task.

If difficulty is to be defined as that characteristic of the task which makes it produce a rapid and large decrement in efficiency in its performance, then the difficulty of a task could be determined by finding the shape of the work curve in the task, i.e., the fatigue decrement, when other factors are constant. Tasks producing rapid and large decrements would be classed as relatively difficult and those producing small decrements would be classed as relatively easy.

FATIGUE

Studies of fatigue have attacked the problem from three quite different angles. Some have defined fatigue in terms of the subjectively observed feelings of fatigue as these show themselves in ennui, boredom, dissatisfaction with the task, and feelings of bodily weariness and an unpleasant affective tone. All these can be grouped under the term Subjective Fatigue. Others have been concerned with changes in the level of performance or output as a result of continuous work. This can be called Objective Fatigue. Still others have taken the position that physiological changes within the organs constitute the real basis of fatigue, and that the term should be applied to them. This can be spoken of as Physiological Fatigue. If any two of these three variables were correlated with one another the problem would be simplified, but as a matter of fact, each one is to a certain extent independent of every other. Neither subjective feeling nor output is highly correlated with physiological condition; nor are subjective feeling and output closely related. Output has a much less rapid decrement than subjective feeling. As a result of these discrepancies some psychologists, notably Muscio and Watson, have argued that the term fatigue is essentially ambiguous and should be eliminated from discussions of work and fatigue. Certainly there is no entity *fatigue* which is independent of these various criteria; but the term is so well established that it seems more practicable to continue to use it with a careful definition of exactly what is implied, than to try to eliminate it.

Nature of Fatigue in Mental Work. — From previous discussion it is possible for us to state what is implied in the concept of physiological fatigue from mental work. Since mental work involves the operation of complete sensory-neuro muscular arcs we may expect to find the following elements in mental fatigue:

(a) Fatigue of sense organs involving eye strain, etc., and resulting in a decreased sensitivity to stimulation or heightened sensory threshold.

(b) Muscular fatigue resulting from the accumulation of toxins in the muscles which decrease the permeability of motor end plates, etc.

(c) The fatigue within the nervous system itself involving heightened synaptic resistance and possible changes in the fibers also. Dodge has taken the position that nervous fatigue is a function of the refractory phase phenomenon in nerve and is to be considered as a biological protective device to guard the nerve against exhaustion. Hence the inhibition of function due to so-called nerve fatigue should rather be considered an automatic protection against fatigue. Breakdown in mental tasks which finally occurs would be the result of accumulative refraction.

CRITERIA OF EFFICIENCY

The main criteria of level of performance in mental work are four in number: speed, accuracy, effort, and satisfyingness. The first two might be called product criteria, the last two process criteria. Many attempts have been made to combine speed and accuracy into some common measure, but without success. Some investigators have combined them by penalizing speed scores with a constant time penalty for each error made. But this involves false assumptions such as that all errors are of equal value and that errors can be evaluated in terms of time. It seems better to plot the two functions independently.

Effort expended has been measured in various ways. Morgan demonstrated the greater effort expended under distractions by measuring the excess muscular effort put into pressure on the response key and vocalization. The various tests of metabolic rate have likewise been used. Satisfyingness as a criterion must be based upon the introspective report of a subject which can be secured in terms of some rating scale. For example, the usual method has been to have the subject rate himself in terms of a scale of five or more values ranging from feelings of greatest fitness for work to feelings of greatest fatigue. Muscio, for example, used the following values: very fit, fit, average, rather tired, very tired.

THE PROBLEMS

Studies of mental work have been concerned with two main problems or fields of investigation. I. The effect of continuous work on its own efficiency; and II. The effect of other factors on the efficiency of the work being studied, i.e., other kinds of work, and organic and mental conditions extraneous to the task. The former of these problems has been investigated through the work curve. The latter has been studied by comparing the efficiency of the worker in the presence of the particular factor versus his efficiency in its absence.

The Practice Factor

Since work involves the operation of *perfected* habits, it is assumed that practice has already been brought to completion, and that no practice takes place during the period of work. But as a matter of actual fact, practice is almost never completely eliminated from the function studied. It, therefore, becomes necessary to devise techniques for balancing the practice effect statistically. These are known as the methods of practice equilibration. They have been summarized by Robinson as follows:

(1) The method of completed practice, which consists of bringing the subjects to a point of nearly perfect practice before the work experiment is started. This is seldom possible.

(2) The method of predicted learning, which assumes that practice has been carried far enough so that the amount of additional practice effect from a given amount of additional performance can be predicted and discounted.

(3) The method of the control group. It assumes that there is a large enough number of subjects so that two groups, an experimental group which is subjected to the experimental conditions, and a control group which is not, can be considered of equal ability. Any difference in the performance of the two groups is then attributed to the effect of the experimental condition.

(4) The methods of counterbalanced order, in which the order of taking conditions is so arranged that practice is assumed to be equally divided between the two conditions, so that neither one receives a greater amount on the average. This method takes several forms:

(a) The ABBA order, in which one condition receives the first and fourth while the other receives the second and third positions. Assuming a linear practice function, then each condition receives the same total amount of practice; but practice is never linear.

(b) The irregular order, ABAB, BABA, etc., which is used in cases where it is advantageous to prevent the subjects from anticipating the order of conditions.

(c) The simple ABAB order where the precautions of (a) and (b) are unnecessary.

(5) The group and counterbalanced methods combined. The subjects are divided into as many groups as there are conditions of the experiment. Each group is then put through the conditions in a different order. When the results of all groups are averaged vertically, the various conditions are equally affected by practice on the average.

Certain pitfalls exist in these latter methods. The different groups may not all be equally affected by practice. Moreover, when the subject passes from the condition *a* to condition *b* this may be quite a different thing from passing from *b* to *a*. If the groups are sufficiently large these objections become less significant.

THE CURVE OF WORK

THE CURVE of work is a graphical representation of the level of performance or level of output of a worker throughout a period of work. It expresses the relationship between efficiency of performance and duration of work. It, therefore, shows the influence of work upon itself. It may be compared with the curve of learning. The latter expresses the relationship between level of achievement and amount of exercise or practice. This gives us a curve expressing progress. On the other hand the work curve expresses the relation between level of performance and amount of work done. The resulting curve shows fatigue. These two types of curve are compared in Figure 91.

In general the ordinate of the work curve expresses level of performance. This may be expressed in terms of units of work accomplished per unit of time, as, for example, the number of pages typed per hour; or units of time taken to do a given unit of work, as minutes required per page of typing; or the relative satisfyingness of a unit of work, or the effort necessary to accomplish a unit of work, or the errors per unit of work. The abscissa on the other hand always expresses successive units of work which may be time units or amount units. It is now possible to plot the successive points representing the level of performance corresponding to each unit of work time. Thus if during the first work unit the subject works at the rate of five problems per minute, his level of performance at that stage is represented by the point (a); and if during the second unit of work he works at the rate of four problems per minute his level is now at (b). In this way a point has been allocated for each work unit, and these points have been connected by a continuous line. We have a work curve expressing the gradual deterioration of performance level as a result of continuous work. Such criteria as errors and time per unit of work produce a gradually rising curve. Whereas, the amount criterion produces a falling curve. It is assumed in work curve construction that the abscissa units are all equal in respect either to time or to amount. The ordinate units also are supposed to express equal amounts of performance. However, it is necessary to avoid certain unjustified assumptions with regard to the ordinate units. For example, the first point on the work curve expresses the level of performance at which the individual began that particular work period. Sometimes it has been assumed that this represents 100% efficiency for that individual; and that any drop from this level can be computed as a percentage loss in the individual's efficiency. For example, Arai obtained a work curve which fell one half the dis-

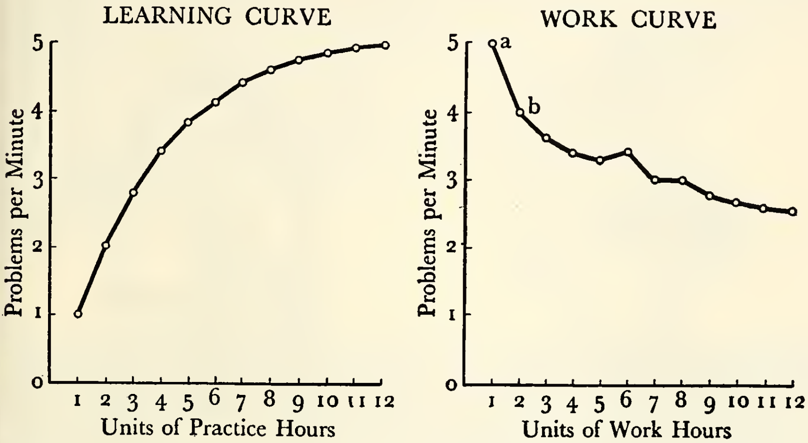

FIG. 91. The curve of work compared with the curve of learning

tance between her initial level of performance and the base line, and she interpreted this to mean she had lost 50% of her efficiency as a result of a day's work. That this is an erroneous assumption can be shown by pointing out that the initial level of performance does not necessarily represent 100% efficiency for the individual, since the initial level is often times exceeded during the work curve. Hence, if she were only working at say 75% of her absolute efficiency, at the start, she could not be said, therefore, to have lost 50% of her efficiency. It must be recognized that the zero on the ordinate scale is not necessarily an absolute zero.

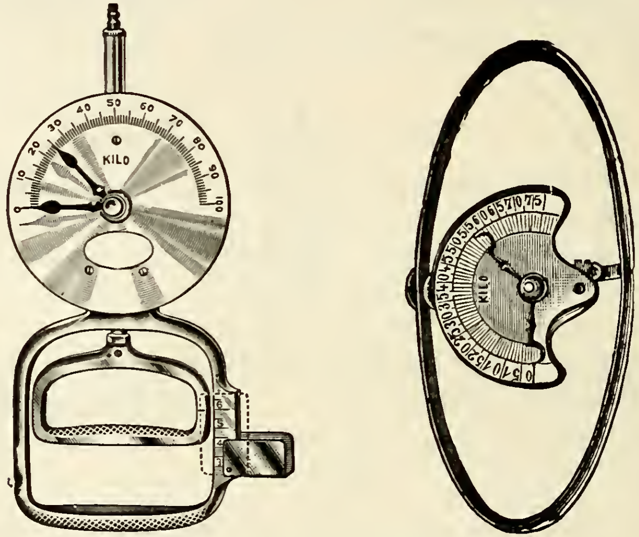

Fig. 92. Hand dynamometers

Courtesy C. H. Stoelting Co.

Methods of Securing the Work Curve

There are two main methods of securing work curves: 1. The continuous work method, and 2. The variations in efficiency method. The former method is to set the subject at a task and note the resulting course of efficiency. To use this method, it is necessary to have a task which can be divided into many equal units, i.e., a highly homogeneous task.

The second method, which is also known as the "Testing Method," and the "Interpolated Task Method," has been used in studying the influence of drugs, diurnal variations in efficiency, and the like. It consists in having the subject work continuously at a task, and then, at regular intervals, introducing tests of his efficiency in performing certain set tasks. The curve is plotted from these test performances and it shows his level of efficiency in them, from time to time through the work period. These tests are of many kinds; the following are a representative sample:

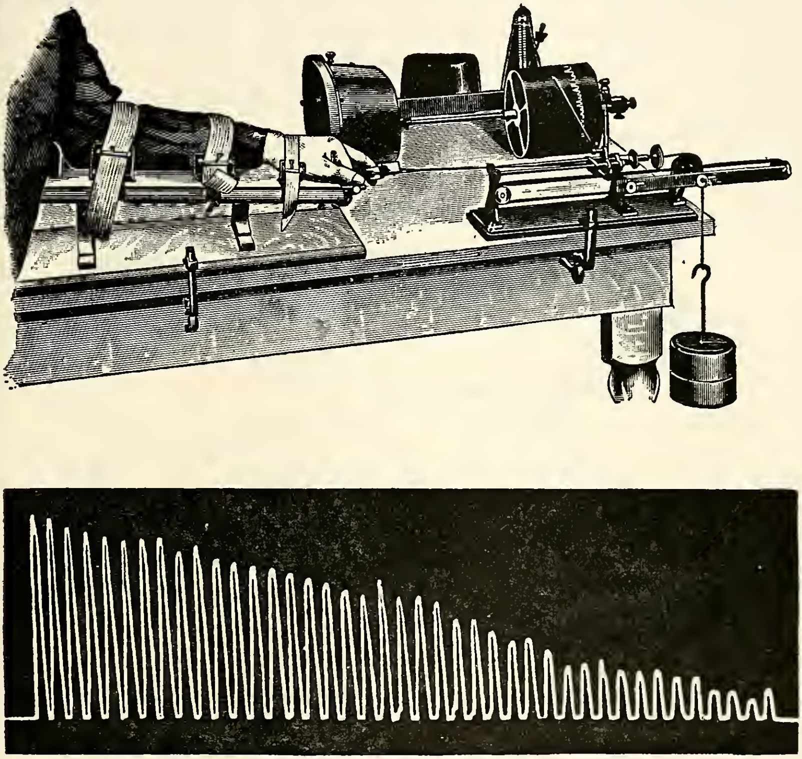

Fig. 93. Ergograph and ergogram

1. Tests of strength of grip on the dynamometer.

2. Tests of physical endurance on the ergograph.

3. Tests of motor speed, such as the spontaneous rate of tapping as registered with a tapping board.

4. Tests of muscular precision and muscular steadiness. These are made by various devices, one of which is the Steadiness Tester, a metal plate pierced with holes through

which the subject is required to thrust a metal stylus. Every contact with the sides is registered electrically and counts as an error. Another is the ataxiagraph for studying body sway and that for measuring tremor of the limbs.

5. Reaction Time tests, to determine the speed of voluntary reaction. These were discussed previously. As a matter of fact, most of the group tests used today are outgrowths of the old cognitive reaction time test. For example, the cognitive reaction time tests performed by Cattell started the modern intelligence test movement, and led to the development of batteries of tests like the Army Alpha Test. Recent examples of laboratory tests designed on the continuous reaction time principle are the McDougall three-hole dotting test, consisting of a revolving band with holes which the subject must pierce as they revolve past a certain point; and the Miles Pursuit Meter, as modified by Renshaw, in which the subject must keep in constant contact with a rapidly moving reference point. The cancellation test, so widely used in mental work, is a reaction time test designed to test speed of perception and constancy of attention, as are memory tests for speed of recall.

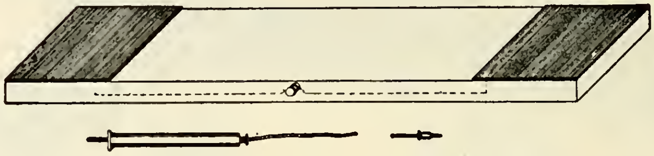

FIG. 94. Tapping board

Courtesy C. H. Stoelting Co.

6. The Association Test, measuring the rate and quality of associational processes.

7. Tests of specific mental functions, as immediate memory, attention, apprehension, judgment, reasoning, and control of imagery.

Still another class of tests of variations of efficiency are aimed directly at the physiological functions. The following are typical:

1. *Calorimetry.* This is designed to determine changes

in metabolic rate, and measures it either *directly,* by placing the subject in a thermally insulated chamber and recording changes in the rate at which he dissipates heat, or *indirectly,* by collecting the products of respiration, and determining the ratio between oxygen intake and carbon dioxide expulsion. This ratio is called the respiratory quotient, and the method is known as Respiratory Calorimetry.

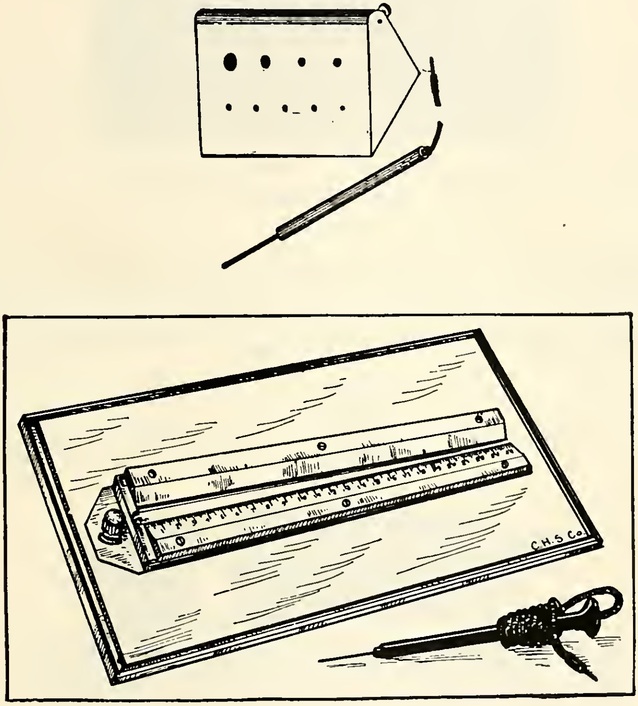

Fig. 95. Steadiness testers

Courtesy C. H. Stoelting Co.

2. *Cardiac Reactions.* These are recorded with a galvanometer and photographed as electrocardiograms.

3. *Blood Pressure.* Measured with a sphygmomanometer. The upper arm is bound with an air cushion tightly enough to stop the blood flow, and then gradually released, so that the number of grams air pressure necessary to just stop the blood flow can be computed. This gives the systolic pressure which

for the average person is around 120 grams. If a continuous record is required, it is necessary to use the Erlanger method.*

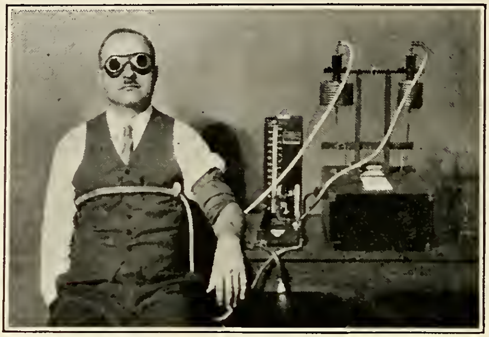

FIG. 96. Subject with pneumograph and sphygmomanometer attached

4. *Blood volume changes.* Measured by a plethysmograph which immerses some part of the body — finger or arm — in a liquid medium and registers changes in its volume.

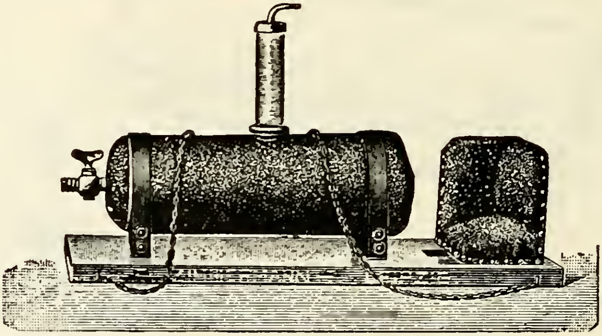

FIG. 97. Plethysmograph for recording variations in blood volume

Courtesy C. H. Stoelting Co.

5. *Pulse rate,* which is either counted by touch or accurately computed with a sphygmograph.
6. *Breathing,* by means of a pneumograph.
7. *Temperature.*

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* According to this method a constant pressure is maintained on the arm cuff at a level considerably below the systolic level so that some blood passes through at every pulse beat. Any change in systolic pressure causes more or less blood to flow through and a continuous graphic record shows these variations, rather than the absolute systolic pressure.

8. *Sensory Reactions.* Among those which have been used are (a) range of accommodation, of the eye; (b) aesthesiometry, determining the two point threshold; (c) algesiometry, measuring the threshold for arousal of pain; (d) visual and auditory intensity limens.

9. *Muscle tonus.* The degree of tonic contraction of the body musculature, which is assumed to correlate closely with the state of fatigue of the organism.

REFERENCES

Arai, T. Mental fatigue. *Teachers College Contributions,* 1912, 54, 1–115.

Dodge, R. The laws of relative fatigue. *Psychol. Rev.,* 1917, 24, 89–113.

McDougall, Wm. The physiological factors of the attention process. Mind, 1902, 11, 316–351.

Miles, W. R. A pursuit pendulum. *Psychol. Rev.,* 1920, 27, 361–376.

Morgan, J. J. B. Overcoming distractions and other resistances. *Arch. Psychol.,* 1916, 35, 1–84.

Muscio, B. Feeling-tone in industry. *Brit. J. Psychol.,* 1921–1922, 12, 150–162.

Muscio, B. Is a fatigue test possible? *Brit. J. Psychol.,* 1921, 12, 31–46.

Renshaw, S., and Weiss, A. P. Apparatus for measuring changes in bodily posture. *Amer. J. Psychol.,* 1926, 37, 261.

Robinson, E. S. Methods of practice equilibration. *Amer. J. Psychol.,* 1929, 41, 153–156.

Thorndike, E. L. Educational psychology. Vol. III. Mental work and fatigue. N. Y. Teachers College, 1914, pp. 408.

Watson, J. B. Psychology from the standpoint of a behaviorist. Phila.: Lippincott, 1924, pp. 369–372.

CHAPTER XXII

WORK CURVE PHENOMENA

AN ANALYSIS of the typical curve of work brings out certain outstanding features which have been experimentally isolated and verified. Historically we owe to Kraepelin and his students the credit for the pioneer investigation of these phenomena. In a series of studies, using simple relatively homogeneous mental tasks, such as the Kraepelin addition test, they isolated some nine constant characteristics of the curve. Not all of these were found to be present in all curves, however. Some of them appear to depend on the nature of the task. The outstanding characteristics to which they gave attention are (1) Initial Spurt, (2) Warming-Up, (3) End Spurt, (4) Practice Effect, (5) Adaptation to Fatigue, (6) Spurts after Fatigue, (7) Spurts after Distraction, (8) Rhythms of Attention, and (9) Fatigue Effect or General Decrement. By far the most constant of these, and the most important, is the General Decrement.

Thorndike has criticised the analyses of Kraepelin on the ground that they have tended to overemphasize minor variations. It is his contention that the work curve, when freed from daily eccentricities, approaches very nearly a horizontal straight line. This is a question of fact, and subject to test. But his criticism is also directed against the apparent tendency to reify concepts like warming-up, initial spurt, etc., as though they were explanatory principles accounting for the work curve phenomena, rather than mere descriptive terms applied to the objective phenomena themselves. For example, there is a tendency to assume, when one of these phenomena fails to appear, that the principle is really present and operating, but that it fails to show up because some other factor is obscuring it. If the fatigue effect fails to appear, it is because the practice effect is obscuring it, not because there is no fatigue. There is some justice in the criticism but, as will be shown, fatigue can be objectively demonstrated even in work curves showing no decrement.

WARMING-UP AND PRACTICE

Two general tendencies or trends are observable in curves of continuous work, one trend toward a rise in performance level, the other toward a fall. The fall is attributed to fatigue. The rise, on the other hand, seems to be a function of two factors; one of which involves a permanent change in capacity, while the other is only temporary, disappearing with cessation of continuous exercise. The former factor is practice, the latter has been called " warming-up." These two factors may be different manifestations of the same fundamental process, but they behave quite differently. It is possible to isolate them and study them separately, in the following way. Since fatigue is defined as that condition of lowered efficiency which is removable by rest, we can assume that a day's rest will remove a normal fatigue decrement, and that, other things being equal, a subject should begin work, after a day's rest, at the same level at which he started on the previous day. Now if, instead, he begins at a *higher* level than previously we must assume that a practice effect has carried over to the following day. By comparing the initial levels of the curves on the two days we can arrive at a quantitative measure of the practice effect resulting from the first day's work. Actually this practice effect was present at the end of the first day's work, but it was not evident from the curve, because fatigue was also present.

But sometimes the work curve rises instead of falling, at least for a time. Part of this is practice and can be determined by the method just suggested. But if the rise on a given day is greater than the amount which carries over to the succeeding day, then something beside practice must account for it because practice is defined as that improvement which carries over. Let us call this something " warming-up" and it then becomes possible to measure warming-up quantitatively by subtracting the permanent improvement from the gross temporary rise. If the gross rise is called "raw warming-up" and the permanent improvement is considered practice, then the remainder constitutes "net warming-up." The formula would be as follows: —

Net warming-up = raw warming-up — practice.

Warming-up could then be defined as that improvement in performance level resulting from continuous work which disappears after rest.

Just what the phenomenon is physiologically can only be guessed at. It is recognized in all sports and physical activity where speed and accuracy are required. Baseball players warm up, typists warm up, pianists warm up. It has been suggested that the presence of a small amount of lactic acid and other products of exercise in the muscles and nerves is beneficial to performance and that only an excess causes lowered efficiency.

Nevertheless it is possible to experimentally determine some of the conditions of work which favor the appearance of warming-up. It is not always present in curves. Robinson suggested that one determining factor is the continuity of performance; a certain degree of discontinuity being necessary for the appearance of warming-up. The following experiment was therefore performed by Robinson and Heron:

Twelve subjects tapped according to the following conditions: They either tapped for ten minutes straight without rest, or else they tapped five minutes then rested a certain time and then tapped five minutes more. Several different lengths of rest periods were used, from ten seconds to 120 seconds. The amount of warming-up was computed by determining the increased number of taps during the second five minutes over the first five minutes, and subtracting from this warming-up the practice effect which persisted to the next day's work. The results show an absence of the warming-up effect for the conditions with zero, ten, and twenty seconds rest, and the presence of that effect for the conditions with forty, eighty, and one hundred twenty seconds rest. It is concluded that the relative discontinuity of the last three conditions enabled the warming-up effect to appear, which was present, but concealed by fatigue in the first three conditions.

In a second experiment the activity consisted in reciting the alphabet backwards. Three conditions were employed.

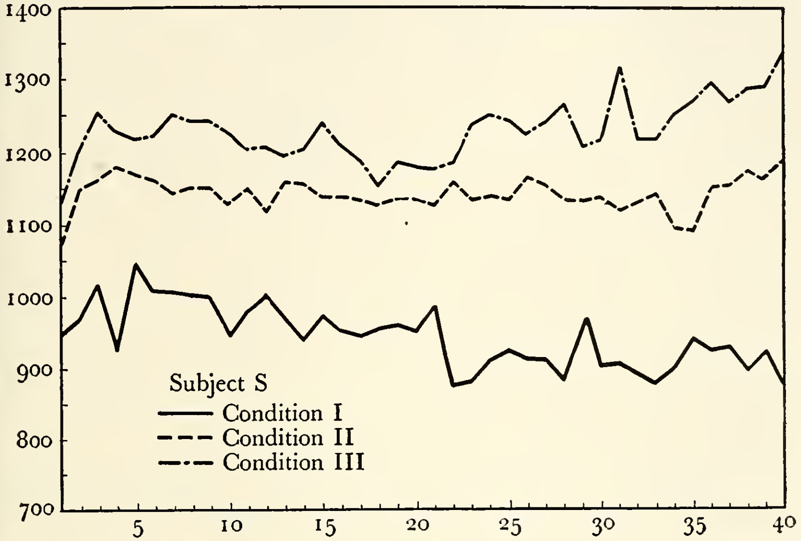

FIG. 98. Warming-up curve

From Robinson and Heron in J. Exper. Psychol., 1924, p. 95, Fig. 5.

(1) Reciting the alphabet backwards continuously for twenty minutes.

(2) Reciting for thirty seconds and resting for fifteen, etc., for twenty minutes of actual work.

(3) Reciting for thirty seconds and resting for thirty, reciting for thirty and resting for thirty, etc., for twenty minutes of actual work.

The resulting curves shown in Figure 98 show warming-up to appear consistently in the early part of the discontinuous conditions, whereas fatigue sets in immediately in the condition of uninterrupted work. Similar findings had previously been reported by Wells in a tapping experiment, and by Kraepelin and his students in various studies on length of rest period.

FATIGUE AND PRACTICE

Fatigue has been defined as that loss of efficiency as a result of continuous work which can be eliminated by rest. Practice on the other hand is that increase in efficiency of performance which tends to persist. Since it is almost never possible to bring the subjects to a condition of 100% practice in the activity before obtaining the work curves, it is practically always true that the work curve contains within it both the effects of the practice and the fatigue factors. Either no decrement occurs in the curve or the decrement is less than it would be if practice were removed. Several methods of eliminating practice statistically have been given. A further procedure is the following: If the subject works continuously for a certain period and then rests for an adequate interval, say of one or more hours, and is then tested again for his level of performance, it is found that the new level is considerably higher than the point at which he left off. The difference between the levels before and after the rest may be considered to be a measure of the amount of fatigue present at the end of the continuous work. Thorndike has suggested a formula for the fatigue developing in a given function from a given amount of work, which we have simplified to the following form: $F = Pwxry - Pwx$, in which P equals the initial unfatigued productivity; Pwx equals the productivity after x hours of work, and $Pwxry$ equals the productivity after a rest of y hours following the x hours' work.

Where the practice factor is not present, however, the fatigue may be computed directly in terms of the general decrement in the work curve.

The General Decrement

Whenever a task is carried on long enough the work curve shows a drop which may be more or less rapid depending on the nature of the task and other things. This is known as the general decrement. It has been computed in various ways by investigators. The most common method is to subtract the average level of performance during the second half of the work period from the average level in the first half.

This has the advantage of simplicity and uniformity, but is open to the objections that it minimizes the amount of the drop, and it puts an artificial dividing line in the curve. Perhaps the drop occurs in the first quarter of the curve and is followed by a rise; or perhaps it occurs so late in the curve that it is averaged out in the last half. In other words, one can conceive of decrements in curves which would be completely concealed by this method. On the other hand, any other method has drawbacks. It is hardly legitimate to take the difference between the first and last points on the curve, because of the large element of chance fluctuation in single points, and the distorting effect of initial spurt and end spurt. To take the highest and lowest points is inadequate because a curve might have a general downward trend as a whole and yet have its highest single point in the second half.

Oehrn, in measuring the effect of fatigue and practice, used the following formulae:

$$\text{Practice} = \frac{(M\text{-}m_1) \times 100}{M}$$

$$\text{Fatigue} = \frac{(M\text{-}m_2) \times 100}{M}$$

where M stands for the point of maximum efficiency, m_1 for the first point of minimum efficiency and m_2 for the second. Obviously, he is using "practice" as synonymous with warming-up, and assuming that the curve will always contain warming-up. If it did not, then there would be no m_1 and the maximum efficiency would come at the beginning. The fatigue formula would remain the same. Oehrn, by stating fatigue as a ratio between the drop and the maximum level, makes it possible to compare fatigues in different curves, having different maximum levels.

Experimental Findings

Experimental studies of mental fatigue may be divided into those which attempted to gauge the degree of loss of efficiency by tests of certain functions supposed to be good indices of fatigue, and those which studied the decrement in the task itself. For example, Mosso and others used motor efficiency on the ergograph before and after mental work as an index of fatigue. At a certain period historically, the skin sensibility test was highly thought of and fatigue was measured by the increase in size of the two point threshold. Greisbach, Binet, and others used this method in studying fatigue of school children, as a result of the regular school day. But the technique was later discredited, not only because of its essential inexactness, or the obviously questionable assumption on which it rested, but because later investigators, Leuba, Germann, Bolton, and others demonstrated that, when carefully taken, the two point threshold showed no change after mental work, such as two hours of addition.

By far the more fruitful method is the direct study of the decrement in the task itself. Among the earliest significant studies is one of Thorndike in which he developed his by-products theory of fatigue as opposed to the mechanical. In his first experiment, four subjects were tested in the morning, before work and at night after a day of mental work; also before and after continuous work on a specific mental task. He found that as a result of two or three hours mental work, the effect of fatigue was not great enough to outweigh the practice effect. In his second experiment, on school children, tests were made before and after the school day. Written multiplication of four place numbers, marking misspelled words, and writing numbers and nonsense syllables from memory were among the functions tested. The only function to show any loss was the memorizing of nonsense syllables, and Thorndike concludes that mental efficiency does not suffer from a day's work. In a later study on eighteen college students, Thorndike found that the capacity to do mental multiplication of three place numbers suffered an average decline of about thirty-nine per cent as a result of from two to twelve hours continuous work. Feelings of fatigue bore no close relation to efficiency. Ellis and Shipe had obtained negative results on trained adults, when they tested efficiency in addition, and memorizing nonsense syllables, before and after a day of hard mental work. Winch, on the contrary, found that immediate memory suffered a loss in improvability during a school day of about five per cent, as did ability to work arithmetical problems, in the younger children. He found the loss to be a function of age, and to decrease with increase in age level.

A significant series of investigations was made by Kraepelin and his students. The pioneer study was that of Oehrn, 1889. Using ten professors and graduate students as subjects, he obtained work curves for one hour's continuous work on simple tasks, involving perception, memorizing, controlled association, as in simple addition, and motor speed, as in writing from dictation. He gives a good description of the work curve for one hour's work. The curve rises for a time, then falls. He attributes the rise to practice, the fall to fatigue, though he obviously includes warming-up in the term practice. The point of maximum efficiency varied with the task, coming earlier in the more automatic tasks (excepting nonsense syllable learning). It came at the 24th minute in learning nonsense syllables, at the 26th minute in writing, at the 28th in addition, at the 38th in reading aloud, and at the 59th in counting letters by three and learning numbers. The amounts of decrement from the maximum level to the minimum varied from 6 per cent in reading, to 38.5 percent in learning nonsense syllables.

Hylan and Kraepelin were interested in the effect of practice and fatigue in very short working periods of five minutes. The work consisted in addition of one place numbers. They found that an appreciable amount of practice and fatigue developed in the short period. The amount varied with individuals. Practice gain was computed from the increase in average amount of work done on successive days. Later work with numbers suggests that the drop which they obtained in these short work periods was identical with what is now considered merely a drop following the initial spurt and may be followed by a quick recovery, or at least a leveling off of the curve.

Arai's Experiment.—In 1910, Tsuru Arai undertook a thorough investigation of the mental fatigue problem, which was epoch making because of the inclusiveness of her results.

On account of its significance for later work, this experiment will be considered in some detail. But since Arai was really interested in four distinct problems, i.e., the influence of fatigue in a mental task, (1) on physiological processes, (2) on feelings of weariness, (3) on other mental processes, and (4) on the particular mental function exercised, only the last aspect of the study will be enlarged upon here. Four experiments were performed, of which only two will be considered. The first was made on Arai herself as subject; the last on a group of sixteen Columbia students and professors. The constant mental task was mental multiplication of four place numbers in Experiment I and of two place numbers in Experiment IV.

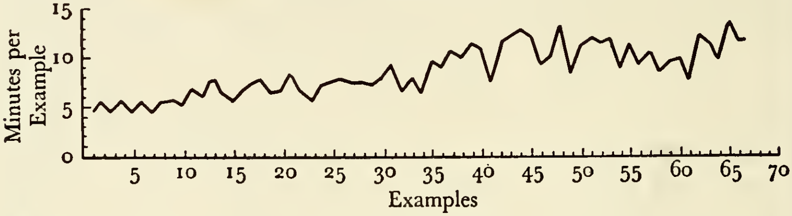

FIG. 99. Eleven hour work curve for mental multiplication

From Arai in Columbia Univ. Teachers College Contrib. to Education, 1912, No. 54, p. 91, curve 12.

In Experiment I, Arai multiplied four place by four place numbers in her head continuously from 11 A.M. to 11 P.M., without pause, on four successive days. She had previously practiced herself in the function throughout the previous month, so that she had reached a high degree of initial proficiency in performance. In fact the average times per example on the four successive days of regular work only decreased from about 9½ on the first day to 7½ on the last. Her introspective observations show no great subjective fatigue after any except the third day's work, although she complains of extremely poor associative capacity toward the end of the first day. Following the entire week's concentrated effort, she says, " I am as cheerful as usual. Physically and mentally, no effect of the hard work seems to remain this morning."

The curve of work which she obtained is a combination speed-and-accuracy curve, since errors were converted into time by penalizing ten seconds for each wrong multiplication. The average loss from twelve hours' work is found to be over half the initial speed. The curve representing the course of efficiency is given in Figure 99.

It is an average curve for the four days of continuous work. It will be seen that the time taken per example has increased from about five minutes for the first example to about eleven minutes, or a little over twice as long for the sixty-seventh example, which marked the termination of the day's work.

Accuracy has also decreased, but not as much. The average number of errors for each of the groups of ten examples is as follows: —

Groups of ten examples	1	2	3	4	5	6	7
Average number of errors	1.8	1.4	1.8	1.6	1.9	2.4	2.7

The irregularities in the curve increase considerably in the latter half. This increased variability of performance is obviously a fatigue symptom, showing loss of control.

In Experiment IV, Arai used sixteen subjects, most of whom were professors and graduate students in psychology. They worked continuously for two or three hours on multiplying mentally two-place numbers by two-place numbers. At the end of the work period, a rest was given and the subject was retested after it. Three lengths of rest period were used: ten minutes, an hour, and three hours. In computing fatigue in this case, Arai used the formula which Thorndike suggested, i.e., the ratio between level of performance at the end of the two hours' work, and that at the end of the rest following the work. Arai found that most of the fatigue had disappeared at the end of ten minutes rest. Using this ratio as a measure of the decrement, she found that the average amount of decrement for the group was 24.2 per cent of the efficiency after rest.

Accuracy failed to show a decrement during the two hours, and in some cases actually improved. The work curves of the various subjects fell roughly into three types: (1) a curve which rises first, then falls suddenly in the last quarter of work; (2) one which falls at first, then rises in the second or third quarter; and (3) one which falls gradually with no clear point of maximum efficiency where fatigue overcomes practice. Type 1 required an average time per example of 123 seconds; type 2, of 104 seconds; and type 3 of 48 seconds. Arai therefore concluded that type 3 curve is that of the best performers.

The conclusions to be drawn from this phase of Arai's investigation are that the decrement from continuous mental work is not large except when the hours of work are unusually long, and that even then the capacity for mental work does not break down completely, as does that for ergograph work. If this is a general characteristic of mental work as opposed to muscular work it is important. In the case of the ergograph, if the subject shifts to a slightly lighter weight, the work can again be continued for a time.

As a result of a suggestion of Thorndike's that at the end of a long period of mental multiplication of four-place by four-place numbers, tests of three-place by three-place, two-place by two-place numbers, etc., should be tried, Painter planned the following experiment on himself: After practicing an hour a day for fifteen days on mental multiplication, during which time he gradually increased the difficulty of the task from two-place to four-place numbers, he set out to work continuously until he should reach exhaustion in the four-place number task, planning then to shift to the easier three-place and two-place multiplication. He started in at 11:00 P.M. on Friday evening after a week of hard mental work. During the first hour there was little subjective fatigue, but early in the third hour the inability to hold partial products in mind or banish the distracting thought of previous ones became acute. By 2:35 the mental process seemed no longer under voluntary control. When Painter tried to drop to simpler problems, as three-place by three-place numbers, etc., he was unable to solve these either.

In fact no mental work of any kind seemed possible, and bodily fatigue was extremely acute by 3:00 A.M. when he had to be assisted to bed by his wife. Painter concludes that "there exists a definite and relatively abrupt appearing point beyond which mental work becomes impossible."

Painter's work curve is suggestive. He succeeded in working twenty-eight problems, the 29th never being completed, whereas Arai worked sixty-seven. Painter required 315 seconds for the first and 1465 for the 26th problem, or close to five times the amount of time per example. Yet until the twentieth problem, the curve is nearly level. Accuracy shows some decrement but relatively much less.

The direct contradiction between these results and Arai's seems to need explanation. Certain differences are evident. The greater amount of previous practice which Arai had is not important, for fatigue decrement is greater after practice; but the difference in time of day is significant. Painter was already fatigued, and was working during hours habitually devoted to sleep. He was interested in watching his condition and feelings, while Arai was always intent upon "getting a true result," or making a good showing. Since there is no way of determining whether they both maintained their maximum rate or not, we cannot tell whether Painter drove himself harder than Arai or not. The latter may have assumed a more leisurely rate. Their initial rate per problem was about equal, i.e., five minutes per problem. A racial difference in fatiguability may have affected the result. A preliminary test of differences in fatiguability of Japanese and American subjects does show a slight difference. Doubt at least is cast upon the universal applicability of Arai's finding.

Recently Reed studied the decrement from a ten hour work day in addition. Eight college students took part. The task was adding examples containing five two-place numbers. This is probably considerably easier than mental multiplication. A midday rest of thirty-five minutes was taken which probably vitiates the results somewhat. Another important point is that the subjects had only practiced the task once before the test period. Hence practice was doubtless large.

For this reason the author employed Thorndike's method of obtaining a ten minute record of performance on the morning following the work day. He then compared this with the record for the last ten minutes of the ten hour work day, and called the difference the fatigue loss. But there is an obvious spurt in his final ten minute record. Therefore, a truer ratio is that between the average ten minute performance in the last work hour and in the ten minutes after rest. This shows a fatigue decrement of twenty-seven percent for the ten hour day. The figure is obtained by subtracting errors from number correct and hence is a combination speed-accuracy score. Accuracy alone fell off more rapidly than speed alone.

It has been suggested by Poffenberger and others that fatigue in mental work may develop rather rapidly, but may be recovered from equally rapidly as a result of rests which are permitted by the nature of the task, in relatively complex tasks, as in transferring from one unit of work to the next. Kraepelin, it will be remembered, obtained considerable decrement in five-minute work curves, and Poffenberger and Tallman report that in one-minute work curves on naming opposites, addition, color naming and cancellation, decrements of from four to thirteen percent were obtained between the first and second half minutes of work. However, this slump which occurs so early in the curve is probably a special phenomenon, associated with initial spurt, to be treated in the discussion of spurts.

The preceding studies give a picture of the general course of fatigue in mental work, and some idea of the amount which is likely to develop. But they do not answer the most important question, i.e., what are the factors which determine the amount of decrement in a given task? Beyond suggesting that the decrement varies in terms of difficulty of the work, there is nothing to show what tasks are most fatiguing or least fatiguing. And difficulty has not been adequately defined.

Principles of the Work Decrement

One necessary procedure in studying the principles governing decrement is to analyze the task in terms of the simple stimulus-response elements involved. As long as mental multiplication is compared with judging compositions, and the like, little progress can be made. Extremely simple operations must be studied in which the stimulus-response elements are relatively isolated. With this in mind, Robinson performed a series of studies designed to discover the main principles of the work decrement. He first formulated a series of hypothetical principles, as follows: —

The work decrement of a given S–R (stimulus-response) connection is relative to the following factors:

1. *The recency of the previous functioning of that connection.* This is an application of the physiological principle of refractory phase, already explained, which Dodge has applied to mental fatigue. An S–R connection is rendered weaker for a short time after its previous functioning.

2. *The frequency of the previous functioning of that connection.* This brings out the added point that refractory phase is cumulative. After a connection has been exercised a great number of times it may reach a breakdown in functioning or a prolonged refraction.

3. *The connections between that S and other R's.* This points to the fact that when a given S is excited, it may be associated with more than one R outlet. The result is a competition for control in which that R outlet whose threshold is lowest at the moment is the one receiving the discharge. But since an important factor in threshold levels of arcs is their condition of previous functioning, there would be a constant tendency, in the continuous functioning of a particular S–R arc, for it to become enough weakened so that other R's would gain control and block the process. Dodge has expressed the same idea in his first law of relative fatigue, to the effect that "In any complex of competing tendencies the relatively greater fatigue of one tendency will tend to eliminate it from the competition in favor of the less fatigued tendencies."

4. *The strength of that specific connection.* This applies not only to the preceding situation, but to the general fact that the strength of a connection determines its susceptibility to decrement. Practice would be one important factor determining such strength.

5. *The qualitative and quantitative integrity of the S throughout the work period during which the work develops.* This recognizes the fact that the S is not necessarily identical either qualitatively or quantitatively throughout a period of work. The work itself may cause qualitative changes in the stimulational conditions. And Dodge has based his first principle of relative fatigue on the fact of quantitative changes in the stimulus intensity which take place during the work process, principally the internal stimulation or motivation. He says, " Within physiological limits all fatigue decrement in the results of work is relative to the intensity of the stimulus." Thorndike's " by-products " theory recognizes the importance of this same principle.

6. *The decrements which have developed in other S–R connections.* This recognizes the fact that fatigue decrements are transferable from one operation to another, so that the size of decrement which will develop in a given system will depend on the various fatigue decrements which have already developed in related systems due to other work previously performed. Transfer is a recognized cause of impaired functioning.

Looking over these six principles we find that each can be characterized briefly by a descriptive term. Principles 1 and 2 affirm that fatigue decrements will be proportional to the *homogeneity* and *continuity* of the work. Principle 3 (taken with 4 and 5) affirms that fatigue decrements will depend on the number of competing tendencies involved, i.e., the amount of *competition* likely to develop. Principle 5 relates to *by-products* of continuous work; and Principle 6 to *transfer of fatigue.*

In testing out the first three principles experimentally, Robinson and Bills performed the following studies. First, in order to quantify homogeneity, a type of task had to be found in which the number of different elements could be systematically varied from one or two, to many. Of course, it would be ridiculous to attempt to isolate a single S–R connection. But it is evident that the continuous writing of a single letter, as "b," involves a more homogeneous neural system than writing two letters or ten letters. Hence one task involved writing, continuously, letter sequences of three different degrees of homogeneity, namely two-letter sequences as ab, ab, ab; three-letter sequences as abc, abc, abc; and five-letter sequences, abcde, abcde. The actual letters used in each condition were sufficiently varied so that the result could not have been due to the difference in difficulty of the letters. The results for one series are shown in the graph above. Each curve represents one condition or degree of homogeneity. It is apparent that there are absolute differences in the levels of performance, the more homogeneous task proving harder from the outset. But this does not obscure the main fact that the degree of fatigue decrement is proportional to the degree of homogeneity, being greatest in the two-letter and least in the three-letter condition. By compelling the subjects, in a later series, to write always in broken sequences,

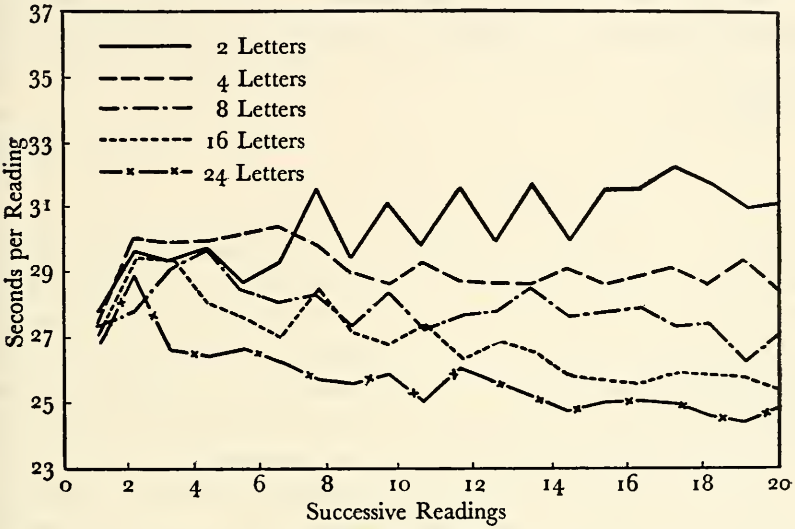

FIG. 100. Relation between homogeneity of the task and degree of decrement from continuous work

From Robinson and Bills, in J. Exper. Psychol., 1926, 9, p. 431, Fig. 10.

i.e., ab — cd — ef, etc., the initial differences in level were removed and yet the relation between size of decrement and degree of homogeneity remained the same.

Results similar to the preceding were obtained in an experiment in which the task was naming of letters, read from a large sheet on which they were arranged in scrambled order. Five different degrees of homogeneity were used in arranging the different test sheets. One sheet contained only two letters throughout; one four; one eight; one sixteen; and one twenty-four. The graph on page 443 shows the results.

The relation of homogeneity to fatigue decrement has since been verified by an experiment of Poffenberger in which work of roughly three degrees of homogeneity was used: (1) continuous addition; (2) judgment of composition; and (3) intelligence test material. The subjects worked a certain period, in the neighborhood of five hours, rested ten minutes and then were retested. The results show the greatest decrement for the continuous addition, about twenty per cent; whereas the Intelligence Tests showed an increment in output of about twenty per cent.

The second principle which was experimentally tested by Robinson and Bills was that of competition. The question raised was this: Will increased heterogeneity of material always decrease decrement, or can material be found in which an increase in the number of elements involved will cause competition, so that the homogeneity-continuity principle will not get a chance to operate? If so, then in this case decreased homogeneity should cause increased decrement. It was necessary, therefore, to discover a task involving elements which were antagonistic with reference to one another, or else so delicately balanced with reference to one another in the total integration, that as a result of continuous operation they would be thrown out of balance and would conflict. The task selected involved simple finger movements, the punching of typewriter keys. Three conditions were used: (1) punching one key continuously with one finger (either the first finger, the second, or the third); (2) punching two keys alternately with two fingers (either the first and second, the second and third, or the first and third); and (3) punching three keys alternately with three fingers. Output was estimated in terms of time in seconds per line of letters punched. Figuring the decrements under the three different conditions during the writing of twenty lines, we find that there is a loss of about 1.1 seconds in speed in the one-finger work, as compared with a loss of 1.6 seconds and 1.3 seconds in the two- and three-finger work.

The experimental testing of principle 6, that of transfer of fatigue decrement, was undertaken later by Bills and McTeer. It will be discussed later under the appropriate topic.

SPURTS IN THE WORK CURVE

In addition to the gradual changes in the level of performance attributed to warming-up, practice and fatigue, investigators have called attention to certain temporary peaks of efficiency in the curve which nevertheless seem not to be chance variations but to obey definite laws. There are four special types: (1) initial spurt, which can best be described as a high initial level of performance at the beginning of the work curve, from which there is a rather sharp drop almost immediately; (2) end spurt, consisting of a high final point at the end of a work curve which is approached rather abruptly from the preceding low level; (3) spurts after fatigue; and (4) spurts after disturbance or distraction. These various spurts were noted and studied first by Rivers and Kraepelin in 1890. Their existence, at least as other than occasional phenomena, has been questioned by Thorndike, but his method of choosing work units was not such as to bring out spurts, as will be shown.

Initial Spurt.—The study of this phenomenon has usually been incidental to the investigation of fatigue. Kraepelin noted that it occurred during the first five minutes of work in such tasks as continuous addition of digits. It has not been by any means a universal phenomenon in all work curves on record and Thorndike definitely took the attitude that until further evidence proves the contrary, it should be considered a chance variation. But the failure to discover initial spurt has in many cases been due to the method of computation or the kind of task used.

There have since been some studies devoted exclusively to the initial spurt phenomenon which demonstrate its reality beyond question. What is needed is an analysis of the kinds of tasks and conditions under which it is most likely to occur. Chapman attempted just this. He points out that previous studies err in using too long units in dividing up the work period, so that the initial spurt could not be found if it were present. Such is the case with Thorndike's study in which five minutes was the unit. There is reason to suspect that most of the spurt occurs in the first minute or two at most.

The same defect applies to Reed's report in which he attempts to discredit initial spurt. His work unit was ten minutes. Even so, he admits that the initial unit tended to exceed later units on the whole.

Chapman, by using a large number of subjects, 46 male college students, corrected another weakness in previous work. The task consisted of addition of columns of ten one-place numbers for ten ten-minute periods. Time was kept by checking in response to a signal given every two minutes. Scores were recorded on the basis of columns added correctly. The results show that in only five of the forty-six cases does the score for the first two minutes of work fail to exceed that for any subsequent minute. The combined total results by two-minute periods read as follows:

First 2 min.	Second 2 min.	Third 2 min.	Fourth 2 min.	Fifth 2 min.
7348	6798	6573	6468	6387

The drop from the first to the second two-minute period exceeds that between any subsequent periods by more than twice. In a later study Chapman and Nolan used even shorter divisions of the work period, i.e., thirty-second intervals. The subjects worked for sixteen minutes. The results are shown in Figure 101.

It will be seen at once that the major drop occurs during the first five minutes and that the use of shorter divisions of time in plotting the curve has greatly enhanced the phenomenon.

F. M. Phillips found that the initial spurt appeared consistently in the first minute of his ten-minute work curves from 100 subjects engaged in addition, subtraction, multiplication and division. He also found that the second minute's record was often poorest in the ten-minute period. L. T. Morgan has recently reported decided initial spurt in work curves of cancellation, coming in the first half minute. The study of Kraepelin and Hylan showing large drops in five-minute work curves, and Poffenberger's report that more is accomplished in the first half minute than in the second half minute of one-minute work periods in color naming, number checking, opposites and addition, should probably be interpreted as initial spurt phenomena.

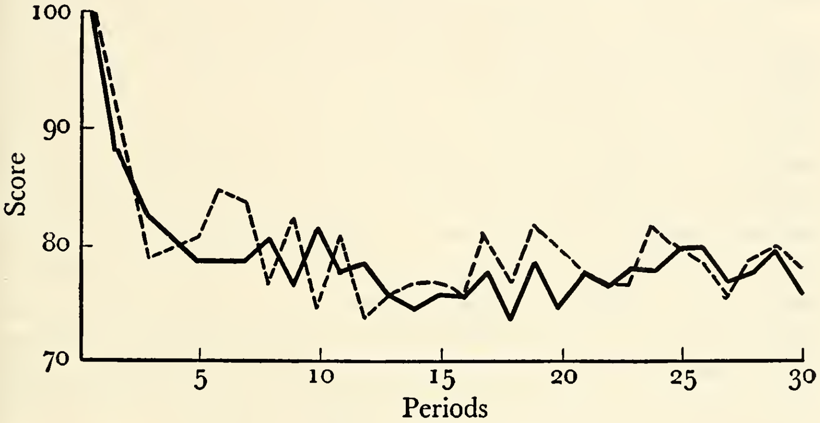

FIG. 101. Showing initial spurt

After Chapman and Nolan, in Amer. J. Psychol., 1916, 27, p. 259, Fig. 1.

So much for the facts. How interpret them? We have shown the phenomenon to be present in certain forms of work. It is not present in all forms. For example, Robinson and Heron's curves for continuous tapping and continuous recitation of the alphabet backward show no such initial high point, even though their time divisions were sufficiently small — one half minute. On the contrary, there is a rise of from ten to twenty per cent in level between the first and second half minutes. What then are the conditions essential for its appearance?

The most strikingly common characteristic of the tasks showing initial spurt is that they all tend to produce associative interference between the elements involved. It is quite possible that the rapid development of this associative interference, until it reaches its maximum, causes the initial slump. The maximum would soon be reached because with either numbers or colors the total number of possible elements is soon exhausted, and beyond that no increase in interference could occur. A saturation point has been reached.

Three other explanations of the spurt have been offered. One attributes it to motivation, the rapid loss of zest and development of mental inertia which occurs as work progresses. But this should continue beyond the first minute or two assuredly. Another reason given is that the subject starts off at a more rapid pace than he is physically able to maintain; the resulting drop represents his rapid adjustment to a speed which is capable of being maintained. The objection to this is that subjects, before practice, when unused to the demands of the task, should show bigger initial spurts; yet this is not the case. And finally there is the possibility that the initial high level represents a high degree of initial concentration of attention. Such attention is never maintained long. All monotonous work very soon passes over into a stage of semi-automatic control, and the individual is able to carry on while thinking about other things. Any one or all of these explanations is possible. Bills and Brown have demonstrated that there is a rapid increase in muscular tension accompanying the drop from the initial spurt, implying some profound alteration of neuro-muscular control during this period.

End Spurt.—While this rise at the end of a work curve is supposed to appear only when the individual is explicitly aware of the fact that the end is approaching, nevertheless, end spurts can be obtained with subjects who have not been told how long they were going to work nor warned that the end was approaching. For example, marked end spurts have appeared in the curves of subjects who have worked a constant amount of time on several successive days. The subjects possibly become vaguely aware of the amount of time which has passed in comparison with previous periods. Sharp obtained what appears to be an end spurt in white rats who had been run continuously for twelve successive runs on several different occasions. The interesting thing about the spurt is that it can come at the end of a long exhausting work period when the individual's efficiency has fallen to a low level. It shows that the available energy of the organism can actually be increased by adding an extra incentive or motivating factor. It illustrates what Dodge means by internal stimuli, or a change in stimulus strength.

Spurts after Fatigue and after Disturbance. — Thorndike says, with reference to these, "in mental work in ordinary life, a person may obviously, if he is not doing his best, at any time do a little better to make up for an observed temporary deficiency, however caused. Deficiencies due to disturbance and to fatigue if they acted unevenly throughout a work period might be those noticed and counterbalanced." He goes on to point out, however, that the suggestion that one is doing well should spur an individual just as much as the suggestion that he is doing badly, and that even though Kraepelin and his followers regard each 'drop-rise' sequence in the curve of work as a deficiency caused by fatigue or disturbance which is compensated for by extra effort, actually no one has empirically correlated fluctuations in work curves with disturbances of known character. He points out that if the fall is caused by a disturbance no cause is required for the rise save the ending of the disturbance, and that a fall followed by a fall or a rise by a rise would be a thing needing explanation. This attitude seems reasonable logically, yet the introspective observation of any person who has acted as a subject in a work experiment corroborates Kraepelin's position. The organism is under a constant competitive set or a set to maintain a certain ideal of efficiency. If the individual is not competing against some one else, he competes against himself. Every worker has known the extra tension caused by the realization of falling below his goal. Obviously, a posteriori examination of work curves could not prove or disprove this unless the subject had previously recorded the time of each subjective experience of this sort.

RHYTHMS OF EFFICIENCY

Unlike the preceding spurts there are likewise variations in the output of a worker which occur with a fairly regular rhythm, and can be studied objectively. They are fairly frequent, and consequently require a division of the work period into small units, and are not evident in curves whose work units are over a minute in length.

The beginning of an interest in the possibility of such rhythms came from the theory of attention rhythms which were described in Chapter XX. It was early found that a subject when attending to minimal sensory stimuli would notice rhythms in the intensity of these stimulations. For example, a person listening to the just audible ticking of a watch would notice that the sound disappeared or fell below the threshold of hearing at periodic intervals. In vision it was found that a person attending to a gray ring on a Masson disc failed periodically to see the ring. These so-called attention rhythms occurred at regular intervals, differing however for different sense organs. The periods reached from 2 to 10 seconds, and could be varied somewhat with effort. The original assumption that these rhythms had a common central origin in the cerebrum and were consequently due to fluctuations in a general attention function has since been questioned. If they were due to a central factor, they should be the same for all sense organs and stimuli rather than differing in rate. The variations in rate seem to require explaining them in terms of peripheral mechanisms. As a result, psychologists have ceased to speak of them as attention rhythms, and call them instead fluctuations of minimal stimuli. However, it is still a recognized fact that attention does fluctuate. Billings found that an individual shifts his center of attention with reference to a perceived stimulus about every two or three seconds.

Von Voss, a student of Kraepelin, attempted to demonstrate such rapid fluctuations in output in the work curve. His procedure was as follows:

Von Voss found that if the successive times of working each of a series of additions are recorded, they tend to show fluctuations, the most frequent time length of which is from two to three seconds. These fluctuations are identified by the fact that each one ends with an addition slower than any since the last preceding fluctuation. He concludes that if mere chance were causing the distribution, the most probable fluctuation length would be 1 2/5 seconds, rather than two or three seconds. Hence, he infers that there must be some law of attention governing the fluctuations, and concludes that attention rises to its highest intensity every two to three seconds. It is true that Billings found that attention shifted on the average every two or three seconds. But Thorndike shows that chance would tend to produce just the distribution of reaction times per example which Voss gets, if given the frequencies of appearance of reaction times of 2, 3, 4, 5, 6, 7, or 8 fifths of a second which Voss himself reports. In other words Voss's two and three second fluctuations are a function of the laws of probability.

Flügel reported periodic fluctuations in the curves of 46 subjects working for 20 minutes per day on addition problems. The fluctuations were in the form of sharp drops in efficiency in the last five seconds of each minute, followed by sharp rises in the first five seconds of the succeeding minute. Since a signal "now!" was given at the end of each minute by the experimenter, Flügel assumes rightly that the periodicity of these fluctuations is an artefact. But the fact that there are rhythms at all is taken to mean that subjects who are working at their utmost (his subjects were highly motivated by a money bonus proportional to their rate) cannot maintain a steady rate but must periodically relax. He concludes that the particular periodicity of these relaxations will vary with the conditions, and is borrowed from them rather than being dictated by any constant physiological factor.

While Flügel's rhythmic fluctuations are, in part, artefacts, nevertheless his published records are valuable since one can detect in them evidence for a different sort of periodic phenomenon which we are about to describe, whose presence can be detected because of the small five second units in which Flügel's data happen to be plotted.

Certain students of mental work have mentioned a tendency for blocks to occur in continuous work, brief periods when the subject is unable to react at all and must pause an instant before proceeding. The phenomenon can be demonstrated by repeating rapidly some such word as *banana* over and over. Such blocks seem to be especially characteristic of work having a high degree of continuity and homogeneity. In experimenting with this blocking tendency, Bills discovered that the blocks tend to occur more or less rhythmically, the average frequency being about three per minute. He therefore investigated the phenomenon systematically in various tasks, as color naming; naming opposites; addition and subtraction; code substitution; and reversible perspective. The responses and errors were registered on a kymograph drum at the instant they occurred, so that the exact time between each response could be accurately measured. The following problems were studied: (1) The frequency and length of the blocks as related to the amount of

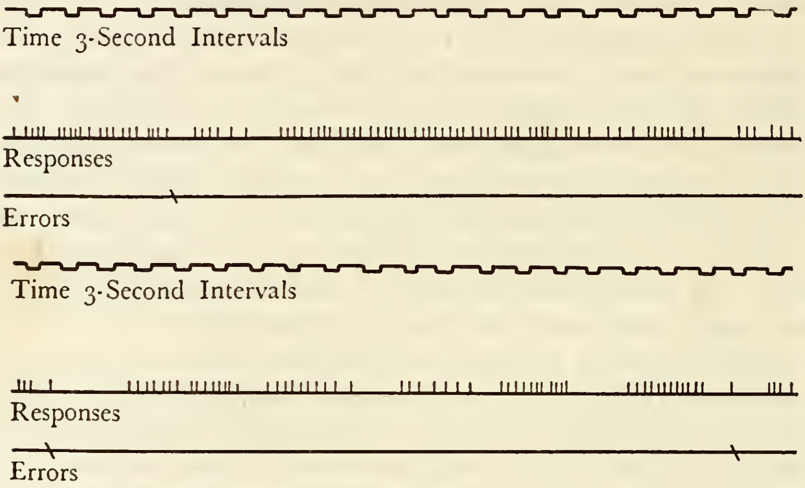

FIG. 102. Effect of fatigue on length and frequency of blocks

The upper lines represent blocking before fatigue while the lower lines represent blocking after fatigue. From Bills in Amer. J. Psychol., 1931, 43, p. 232, Fig. 1.

homogeneity and competition involved in the different tasks; (2) the effect of practice and of fatigue on frequency and length of blocks; (3) the relation of blocks to errors; (4) the degree of rhythmicality in appearance of blocks, and its relation to possible bodily rhythms, and to the refractory phase principle; and (5) individual differences in the tendency to block.

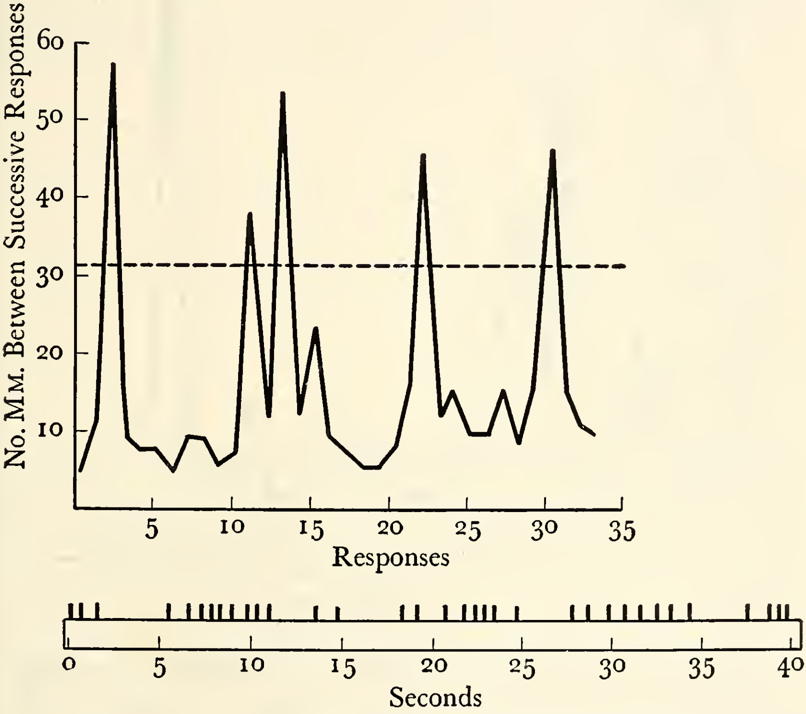

Fig. 103. Appearance of blocks before practice

From Bills in Amer. J. Psychol., 1931, 43, p. 238, Fig. 2.

The accompanying figures will show something of the rhythmicality of the blocks, and the change in their character with fatigue, and with practice. Figure 102 shows one minute sections from the first and last parts of an hour's record. The most striking changes resulting from fatigue are the increase in size of the individual blocks and the increase in their frequency. Between blocks, however, the responses are so much more rapid that the increased blocking does not materially decrease the number of responses per minute.

The effect of practice is brought out in Figures 103 and 104, in two ways. The graphs show the successive responses along the abscissa plotted against their distances apart in millimeters, represented by height on the ordinate axis. Every peak rising above the horizontal dotted line fulfills the criterion of a block. The peaks, then, represent the blocks, and the valleys between represent the bunches of responses occurring close together. It can be seen that the approaches to the blocks are relatively abrupt, and that there results a series of wave-like scallops with bunching up of responses between blocks. Practice tends to make the peaks occur less

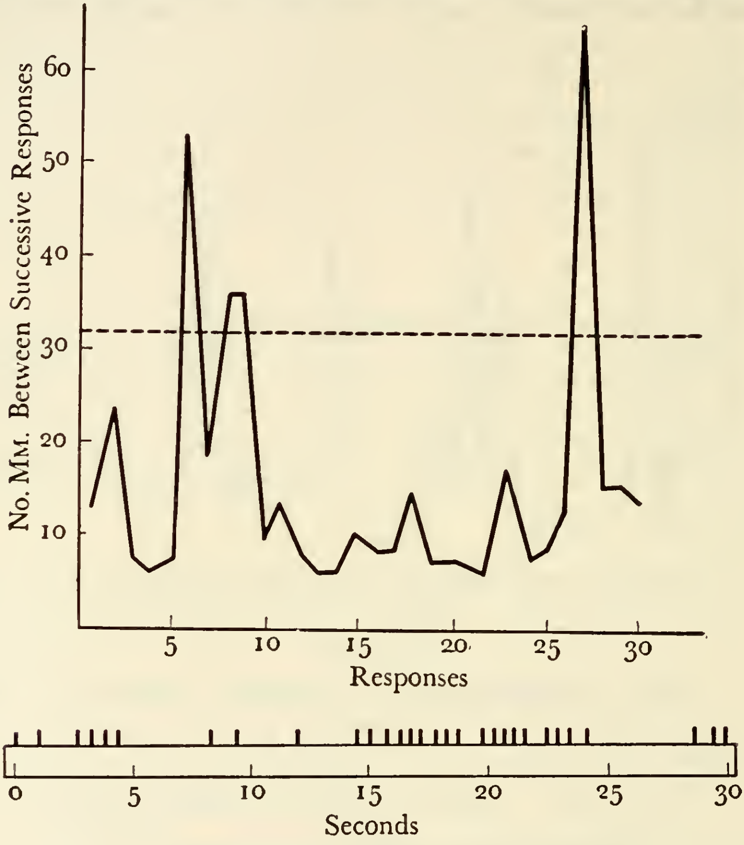

FIG. 104. Appearance of blocks after practice

From Bills in Amer. J. Psychol., 1931, 43, p. 239, Fig. 3.

often. The lower parts of Figures 103 and 104 are merely enlarged reproductions of the kymograph records from which the graphs were computed.

There was a consistent tendency for errors to occur in conjunction with blocks, suggesting that the cause of errors lies in the recurrent low condition of neural functioning which the blocks reveal. The table below shows the relation between errors and blocks in the case of six subjects.

RELATION OF ERRORS TO BLOCKS

		Errors at Blocks	
Subject	*Total Errors*	*Number*	*Per cent*
D	123	77	62.6
R	89	47	52.8
T	70	56	80.0
W	20	14	70.0
P	15	10	66.6
C	7	5	71.4
		Average	62.7

Competition amongst the elements involved in a repetitive task is an important factor in increasing the blocking tendency. This was demonstrated in an experiment on color naming involving three conditions, a two-color, a three-color, and a five-color condition. The colors appeared in scrambled order. All three conditions produced blocking, but the frequency of blocks increased as the number of elements, so that the five-color condition had the most, in spite of the fact that the average speed in this condition was only 2/3 that of the two-color task. The table shows the relation between number of competing elements and number of blocks.

CONDITION	AVERAGE BLOCKS PER MINUTE
2-color	3.0
3-color	3.3
5-color	3.5

When no competition is present, the number of elements involved apparently has little effect on the frequency of blocking.

Individuals differ considerably in the frequency of their blocking, from a maximum of five or six to a minimum of about two blocks per minute. The interesting question is whether the rapid workers block more or less than the slow workers. Correlations show a slight tendency for slow workers to block oftener. Evidently the same trait which is responsible for rapid mental functioning tends also to minimize the need for enforced rests or blocks. To the extent that blocks are related to errors, this agrees with the finding that fast workers tend to be more accurate than slow workers.

When length of blocks is correlated against speed of response, very high negative correlations are obtained, ranging from .70 to .88, showing that the slower workers have the longer blocks, as might be expected.

The interpretation of the blocking phenomenon involves a consideration of the physiology of continuous function of relatively isolated neural arcs. Apparently there is a recurrent condition of lowered capacity of the arcs to function. If the blocks were absolutely rhythmic we would suspect the influence of a constant organic rhythm of some sort, as breathing or heart rate or vaso-motor phenomenon. All these body rhythms were evoked by Pillsbury and his colleagues to explain the attention wave. But simultaneous records of breathing rate and Traube-Hering rate accompanying blocking records fail to show any correlation between these phenomena, with the exception of a slight tendency for blocks to synchronize with the expiration phase of the breathing curve. But all of these physiological rhythms are much too rapid to account for a phenomenon occurring only about three times a minute.

On the other hand we do find a physiological basis for the block in a characteristic of the refractory phase. Recently physiologists, principally Field and Brücke, have discovered that in addition to the simple refraction of extremely short duration which occurs immediately after a single stimulation, there is a longer refraction period which occurs after repeated stimulations, which they consider as merely a prolongation of the simple refraction. This accumulative effect probably accounts for the block. Why the existence of competitive elements in the task should cause more frequent blocks is not certain, but it probably points to some inhibitory process. The surest proof that it is refraction would be to demonstrate a greater amount of blocking with greater homogeneity of work.

ADAPTATION TO FATIGUE

The assumption has been made by some of Kraepelin's students that a process of adaptation occurs where a particular task is repeatedly worked at, whereby the fatigue effect is diminished. It has been noticed that with the gradual automatization of a function, the degree of attention necessary to carry it on becomes less and less. In so far as fatigue is a loss of the capacity for giving attention to the task, this particular aspect of it is removed. Some authors, as Myers, contended that the main factor in mental fatigue is the collapse of the power to attentively control one's complex integrations. Ford in a study of distractors maintains that the decreased efficiency which results either from the introduction or removal of a distracting stimulus during work is due to the extra attentive effort required, and that the ultimate supra-normal efficiency attained under the distractor is caused by adaptation to the situation, rather than to summation of impulses.

REFERENCES

Arai, T. Mental fatigue. N. Y. Teacher's College, Columbia University, 1912, 54, 1–115.
Bills, A. G. Blocking: a new principle of mental fatigue. *Amer. J. Psychol.*, 1931, 43, 230–245.
Bills, A. G., and Brown, C. The quantitative set. *J. Exper. Psychol.*, 1929, 12, 301–324.
Bills, A. G., and McTeer, W. Transfer of fatigue and identical elements. *J. Exper. Psychol.*, 1932, 15, 23–36.
Billings, M. L. The duration of attention. *Psychol. Rev.*, 1914, 21, 121–135.
Bolton, T. L. Ueber die Beziehungen zwischen Ermüdung Raumsinn der Haut und Muskelleistung. *Psychol. Arbeit.*, 1902, 5, 175–234.
Chapman, J. C. A study of initial spurt in addition. *J. Ed. Psychol.*, 1915, 6, 419–426.
Chapman, J. C., and Nolan, W. J. Initial spurt in a simple mental function. *Amer. J. Psychol.*, 1916, 27, 256–259.
Dodge, R. The laws of relative fatigue. *Psychol. Rev.*, 1917, 24, 89–113.
Ellis, A. C., and Shipe, M. M. A study of the accuracy of the present method of testing fatigue. *Amer. J. Psychol.*, 1903, 14, 232–245.
Field, H., and Brücke, E. Ueber die Dauer des Refraktärstadiums des nerven bei Ermüdung und Erholung. *Pflüg. Arch. f. d. ges. Physiol.*, 1926, 214, 103–111.

Flügel, J. C. Practice, fatigue, and oscillation. *Brit. J. Psychol. Mon. Suppl.*, 1928, 13, 1–20.

Ford, A. Attention-Automatization. *Amer. J. Psychol.*, 1929, 41, 1–32.

Germann, G. B. On the invalidity of the aesthesiometer method as a measure of mental fatigue. *Psychol. Rev.*, 1899, 6, 599–605.

Greisbach, H. Energetik und hygiene des nervensystems. *Arch. für Hygiene*, 1895, 24, 124–212.

Hylan, J. P., and Kraepelin, E. Ueber die Wirkung kurzer Arbeitszeihen. *Psychol. Arbeit.*, Vol. 4, 454–495.

Kraepelin, E. Die arbeitscurve. *Philos. Studien.*, 1902, 19, 459–507.

Leuba, J. H. On the validity of the Greisbach method of determining fatigue. *Psychol. Rev.*, 1899, 6, 573–598.

Morgan, L. T. Some characteristics of the work curve with short working units. *Amer. J. Psychol.*, 1926, 37, 402–407.

Mosso, A. Fatigue. N. Y. Putnam's Sons, 1915, pp. 334.

Myers, C. S. Conceptions of fatigue and adaptation. *Psychol. Rev.*, 1925, 32, 1–16.

Oehrn, A. Experimentelle Studien zur Individualpsychologie. *Psychol. Arbeit.*, 1895, 1, 92–151.

Painter, W. S. Efficiency in mental multiplication under extreme fatigue. *J. Ed. Psychol.*, 1916, 7, 25–30.

Phillips, F. M. A comparison of the work done in successive minutes of the work period. *J. Ed. Psychol.*, 1916, 7, 271–277.

Pillsbury, W. B. Attention waves as a means of measuring fatigue. *Amer. J. Psychol.*, 1903, 14, 541–552.

Poffenberger, A. T. The effects of continuous mental work. *Amer. J. Psychol.*, 1927, 39, 283–296.

Poffenberger, A. T., and Tallman, G. Variability in performance during brief periods of work. *Psychol. Rev.*, 1915, 22, 371–376.

Reed, H. B. Fatigue and work curve from a ten-hour day in addition. *J. Ed. Psychol.*, 1924, 15, 389–392.

Rivers, W. H. R., and Kraepelin, E. Ueber Ermüdung und Erholung. *Psychol. Arbeit.*, 1896, 1, 627–678.

Robinson, E. S. Principals of the work decrement. *Psychol. Rev.*, 1926, 33, 123–134.

Robinson, E. S., and Bills, A. G. Two factors in the work decrement. *J. Exper. Psychol.*, 1926, 9, 415–444.

Robinson, E. S., and Heron, W. T. The warming-up effect. *J. Exper. Psychol.*, 1924, 7, 81–97.

Sharp, W. L. Disintegrative effects of continuous running and removal of the food incentive upon a maze habit of albino rats. *J. Comp. Psychol.*, 1929, 9, 405–423.

Thorndike, E. L. Mental fatigue. *Psychol. Rev.*, 1900, 7, 466–489; 547–579.

Thorndike, E. L. The curve of work. *Psychol. Rev.*, 1912, 19, 165–194.

Von Voss, G. Ueber die Schwankungen der geistigen Arbeitsleistung. *Psychol. Arbeit.*, 1899, 2, 399–449.

Wells, F. L. Studies in retardation as given in the fatigue phenomena of the tapping test. *Amer. J. Psychol.*, 1909, 20, 38–59.

Winch, W. H. Mental fatigue in day school children as measured by arithmetical reasoning. *Brit. J. Psychol.*, 1911, 4, 315–341.

CHAPTER XXIII

THE EFFECTS OF MENTAL FATIGUE

FEELINGS OF FATIGUE OR SATISFYINGNESS

THE QUESTION of the relation between variations in output and variations in the subject's feeling of weariness and ennui has been attacked by several students of fatigue, but notably by Thorndike, and Muscio. A recent study of Poffenberger's is concerned with this relationship.

It will be remembered that in Arai's study of mental fatigue she kept careful records of the subjects' introspective reports of feelings. She was interested in three things, the duration and amount of change in feelings; a correlation between the feeling tone at any time and the accompanying level of mental efficiency; and, finally, the correlation between changes in feeling and changes in output. She accepts Thorndike's definition, namely, " Emotional repugnance to the idea of doing mental work." She used three levels of feeling tone, good, medium, and tired. Obviously, this hardly gives enough degrees of feeling tone to obtain very significant relationships. She found a change for the worse as a result of prolonged work especially in the case of her twelve subjects. The correlation with pulse rate and output was positive but low. In her own case little change in feeling tone was expressed.

Thorndike studied the change of satisfyingness as correlated with the work curve of twenty-nine adults in grading printed compositions continuously for two hours. The work was graded for speed and quality, and satisfyingness was scored every twenty minutes from zero to ten, in which zero meant greatest discomfort or aversion ever experienced, five meant average attitude, and ten meant greatest satisfaction with work ever experienced. The work curves for speed quality and satisfyingness were as follows:

	First third	*Second third*	*Third third*
Errors	100	103.8	101.6
Times	100	97.3	100.6
Satisfyingness (in sixths)	4.4 4.0	3.6 3.4	2.8 2.6

In other words while speed and accuracy remained constant throughout the two hours the level of satisfyingness decreased nearly one-half.

Muscio correlated the output and feeling tone curves of a group of twenty women medical students engaged in their regular academic work from 10 A.M. to 5 P.M. They were given three tests every hour in which mental work was performed and an introspective report was taken of their feelings in accordance with four levels; fit, fairly fit, a little tired, very tired. A similar group of data was obtained from fifteen young women typists. The resulting curves show a rapid deterioration in feeling tone, but the correlation with output curves is very slight except in the general trend.

Poffenberger's study was concerned with the decrement developing in four tasks of varying homogeneity; addition, sentence completion, intelligence tests, etc. He took introspective reports of the subjects' feeling tone at the end of every twenty-one minute period during five and one half hours' work. Seven degrees of feeling tone were recorded from extremely good to tired. Arbitrarily designating the initial feeling level as zero, he assigned a plus value to changes toward more unpleasant and a minus value to changes toward more pleasant. Output and feelings were plotted separately. Results show that feelings dropped from the very start, whereas output usually rose. In the intelligence tests there was an improvement of 20% in efficiency with a drop of 1.3 steps in feeling. Among individuals, those who showed the greatest output loss suffered the greatest decrement in feeling tone, but otherwise there was no positive relation between the two functions.

Evidence from many directions tends to show that individuals differ tremendously in their susceptibility to subjective feelings of boredom, monotony, and the like, and the degree to which these influence their objective output. In a recent study of Lewin's designed to discover what he calls the point of " psychic satiation " in mental work, he found that when subjects were required to read the same poems repeatedly or draw very simple patterns continuously, the mental breaking point or point of satiety appeared long before any decrement in rate of output appeared. The subjects tended to compensate for it by varying the nature of their responses in all possible ways, which in most tasks would be equivalent to a decrease in accuracy.

THE PHYSIOLOGICAL EFFECTS OF WORK

THE third aspect of fatigue, that of changes in the physiological condition, has been studied concomitantly with the output decrement. If properly done, it requires the use of biochemical techniques, which are not available to the average psychologist; so that a few physiologists have furnished the most reliable data. The correlation with output is not particularly high.

The problem has been attacked through (a) direct study of metabolic rate, and indirectly through (b) the pulse, (c) the breathing, (d) the temperature, (e) the vascular processes, (f) muscular strength, (g) blood chemistry, saliva, and urine, and (h) changes in the nerve.

Pulse Rate and Breathing

The oldest method, that of recording the pulse rate, has been thoroughly tried out by Dodge. As he points out, the early studies in which changes of pulse rate have been correlated with periods of attention are invalidated in several ways. Most of these studies fail to take into consideration the fact that mental attention involves muscular quiescence. It is necessary to precede the period of attention by a protracted period of absolute muscular relaxation to be sure that this source of error has been eliminated. Another fault is the assumption that attention to some isolated stimulus such as a tone or a ring on a Masson disc is more strenuous mentally or more exciting than the ordinary condition of mental excitation, when the individual's attention is divided amongst a large number of stimuli. These considerations may explain why early investigators found that the pulse rate decreases instead of increasing with attention. A third consideration is that in the act of attention respiration is held in abeyance and this tends to lengthen the time of the heart rate. Billings and Shepard recognized these facts and they therefore measured changes in the amplitude and rate of respiration concomitantly with the pulse wave of subjects engaged in auditory, visual, and central attention. They noted that whereas sensory attention often gave a decreased heart rate, central attention regularly increased the heart rate.

Recently Skaggs compared breathing rate and pulse waves from the right carotid artery, during mental work, during excited expectancy, and during relaxation. The mental work consisted of continuous mental multiplication, and perspective reversal. The state of attentional strain with emotional excitement was produced by having the subjects sit, expecting a strong electric shock. The results show that mental work produces the most shallow, and most rapid breathing, while excited expectancy gives the deepest and most variable. Pulse rate is least in mental relaxation; averaging about 40 per half minute for men. It is increased in mental multiplication to about 43.7; and is still further increased by attentional strain to about 45.8.

Dodge criticizes the work of Benedict and Carpenter who had subjects count their pulse during four hours of mental work on college examinations vs. a resting control. They found an average rate of 79 beats per minute during mental work against 74 in the control experiment. But the conditions of the novel situation, i.e., entering a respiration calorimeter chamber, the necessity of taking their own pulse, etc., produced enough excitement to make the difference of degree of mental activity in the two situations relatively slight.

Arai recomputed their data to determine the actual drop in pulse rate from the beginning to the end of the work vs. the control periods. The average rates were 87.4 and 76.3 for the work period, while for the control period they were 82.4 and 69.9. This gives a drop in rate of 11.1 beats per minute during the work period, and a drop of 12.5 during the rest period.

Benedict and Carpenter had recognized the fact that mental work is usually accompanied by muscular action, as writing or speaking, and that the metabolic effect of this must be subtracted. For this purpose they had the subjects repeat the examinations, merely copying the answers on the assumption that this would involve the same amount of muscular work, with the mental work left out. The assumption is barely justified because copying itself involves considerable mental adjustment. Dodge, in a similar experiment, controlled this factor by keeping a kymograph record of every muscular contraction which the subjects made while performing the examination and by comparing heart rate during such muscular activity with those periods when no overt muscular action occurred. He discovered that the average writing pulse frequency for both halves of the examination period was higher than the average non-writing pulse frequency for one subject; lower for another; and the same level in the case of a third. This is taken to mean that the mental effort of preparing the answers to the questions *may* increase the pulse more than the muscular effort of writing the answers.

Dodge's general conclusion is that " Within the limitation of my experimental data, I can say that, provided one starts from a pre-experimental condition of relatively complete physical and mental relaxation, every new mental or physical activity is correlated with an accelerated pulse."

Arai gives records of her pulse in the morning and evening of each work day and the ratio between them. The amount of work varies on different days, the least being one hour and the most ten hours. Strange to say, she finds the greatest drop in pulse rate with the longest work period, a decrease of about 7.3% of the morning rate; whereas the shortest work periods cause the least drop, or about 1.5%. With her other subjects Arai found a drop in pulse rate of about 13.3% during two hours work. Correlations of about .40 were obtained between changes in objective output and changes in pulse rate. Arai's results, however, seem to be invalidated in this way: During the days when she did little mental work, she probably did much more physical work, since her mental work required sitting quietly. The records were taken at night rather than immediately after work.

The earlier experiments of Vaschide and Larguier des Bancels were invalidated, also, by the fact that they do not state how their rest days were spent, i.e., how much they moved about. Vaschide compared his pulse rate on days when he rested and days when he spent fourteen hours on strict mental work. On working days, the average rate (over 40 days) was 71.04 and on resting days the average (for about 40 days) was 76.86.

L. des Bancels compared his pulse rate during periods of mental work lasting from 8 P.M. to 12 P.M. and during rest periods covering the same hours. The hourly rates during work were 80.9, 72.2, 67.15 and 62.9 respectively, while the hourly rates during rest were 80.4, 69.8, 65.7 and 65.2.

Temperature

It is obvious that temperature and heart rate bear a close relation. But it is also known that the action of nerves in excitation involves the production of appreciable amounts of heat. Gerard, besides demonstrating the production of CO_2 in amounts exceeding that given off by resting nerves, has shown that the heat production from nerve stimulation is delayed, and may last as long as ten minutes after activity ceases.

But it is doubtful whether the slight amounts of heat developed in nerve would appreciably affect gross measurements of a subject's temperature. The muscular inactivity accompanying mental work should cause a fall in temperature. The question is, is this fall greater or less than that resulting from rest? An early study by Gley, 1884, is summarized by Arai: " Gley made two series of experiments on himself. In the first series, the temperature was taken every five minutes during mental work of from one to three hours done between 5 P.M. and 8 P.M. and also during a rest at about the same period of the day. It was found that temperature fell, not only during the mental work but during the rest also. This fall is attributed by the observer to the immobile state which the subject was forced to maintain during the experiment. In the second series, a similar test was made while the subject was in bed, beginning about one hour after awakening in the morning so as to free the subject from the influence due to muscular inactivity. In this test, unlike the results of the other, the temperature rose more than one half of a degree on the average during mental work of about an hour. Gley concluded from the result of these experiments that mental work raises the temperature."

Arai, herself, obtained temperature records before and after her mental work periods and those of her subjects. The results were very variable. Sometimes there was a slight rise, sometimes a slight fall. The average for her was a rise of one-tenth of one per cent F. for two hours' translation work. For her subjects, the average was a drop of two-tenths of one per cent during two hours of mental multiplication. The extreme variability shows that the averages have no significance.

Metabolic Rate

The influence of mental work on metabolic rate has been studied through the respiratory exchange and through heat calorimetry. The first carefully controlled experiment was that of Benedict and Carpenter in 1909. Using a combination of the two methods, they obtained records of the carbon dioxide and water vapor eliminated, the oxygen taken in, and the heat given off by their subjects. The results during four hours of mental work on college examinations were compared with those for an equal period of rest. They found that the water vapor was increased by about five per cent; the output of carbon dioxide by about two percent; the consumption of oxygen by six per cent and the heat production by a half per cent. But there were large individual differences, many subjects producing more heat in the resting state. It was necessary to place the subjects in a complicated respiratory chamber, a novel experience for the majority, and hence productive of mental disturbance which would affect the resting metabolism. The authors were extremely modest in their claims for the study, yet it has remained the classic metabolic experiment in mental work ever since.

Quite recently Benedict (1930) studied the heart rate, and amplitude of respiration, air intake, oxygen absorption, and carbon dioxide elimination, of subjects under three conditions: muscular repose, attention to a sensory stimulus, and while multiplying two-place numbers mentally. He used an improved breathing helmet which removed most of the subject's discomfort and distraction. His earlier findings were corroborated. Metabolic rate was increased though the effect was not cumulative. The average results on heart rate and respiration for six subjects are given below:

EFFECTS OF MENTAL WORK ON HEART AND RESPIRATION

Heart Rate		*Breathing Rate*		*Lung Ventilation in Liters*	
Rest	Work	Rest	Work	Rest	Work
60	65	14	15	5.4	6.2

In 1914, Becker and Olsen performed a series of 60 experiments using two subjects mainly, and measuring metabolic rate by the respiration calorimetry method. Volumetric measurements of inspired air and chemical analysis of expired air were obtained. In a preliminary study they determined separately the effect of waking vs. sleeping, covered vs. uncovered eyes, passive vs. active attitude, emotional vs. unemotional state, and comfort vs. discomfort. All these as well as many other factors are capable of producing respiratory changes. They concluded that measures of metabolic rate should be preceded and followed by at least a half hour of absolute rest to mean anything, because when the subject rested after being slightly active, his rate of CO_2 elimination decreased per second for a half hour, before stabilizing. As in Benedict and Carpenter's experiment, the metabolic effects of writing answers, movements in eyes in reading and all other muscular activities connected with the mental work were tested separately and subtracted from the results. The main task was memorizing nonsense syllable lists of 8, 10, 12, etc., syllables. Testing periods were introduced every ten minutes and the experiments were carried over successive days. The results show scarcely any increase in rate for the muscular activities accompanying the work, but a definite increase with mental effort which was proportional to the amount of effort, or difficulty of the task. The learning by heart of a list of 30 syllables considerably increased the CO_2 elimination. Practice reduced this amount somewhat. Becker and Olsen conclude that "the magnitude of the metabolic increase arising from mental work will oscillate parallel to the subjectively estimated amount of work performed."

Laird studied the increased energy expenditure in such mental tasks as typing at top speed, mental multiplication, learning nonsense syllables, and sustained attention. Weeks of quiet were alternated with weeks of noise. The periods lasted two hours, preceded by a half hour's rest, and samples of air were taken every fifteen minutes. In the noisy phase, the average energy expenditure was 71 per cent higher during work than during rest; and in the quiet phase, only 51 per cent higher. Laird and Wheeler found a much greater increase in metabolic rate from mental multiplication carried on after a loss of a night's sleep than when the same work followed a regular night's sleep.

Vascular Processes

Studies of the effect of mental work on vascular processes are rare. Day investigated the effect of rest, physical activity, and mental activity, on blood pressure and pulse rate, using both adults and school children as subjects. Her results on pulse rate corroborate Dodge, Benedict and others in showing an increase with mental work, but the blood pressure changes showed no consistent influence either from the mental or physical activity. They suggest, however, that with a longer period of preliminary readings to compare the working pressure with, an increase in both systolic and diastolic pressure might be established.

Other Effects of Work

A few studies have been made on the chemistry of the blood, saliva and excretions. Blonsky tested the saliva of a group of Moscow school children just before breakfast. Of these he selected ten children to whom he gave a series of tests in which they were required to solve difficult maze problems. He reports an increased alkalinity. Another group was allowed to rest and let the mind wander. Alkalinity is reported to have dropped in the latter case, from which it is concluded that concentrated mental effort increases alkalinity. The study is not sufficiently controlled to justify definite conclusions. That the blood changes have little direct effect on efficiency has been demonstrated by Shock who artificially induced both a greatly exaggerated alkalinity and a hyperacidity without markedly affecting mental output. Neural effects of fatigue have been studied histologically. The fatigued cell body presents a typical picture of shrinkage of the Nissl bodies due to the using up of the reserve materials in the cell.

TRANSFER OF FATIGUE

The actual performance of any act is carried out by a limited part of the organism. Specific sensory-neuro-muscular systems are involved. The more homogeneous the task the more limited the system. Yet every act indirectly involves the whole organism, and it seems logical to assume that there would be a carry-over or transfer of the effects developed in one act to other acts. The degree of transfer should be roughly proportional to the similarity of the two acts, since similar acts involve related systems. This is the problem of fatigue transfer. To what extent do decrements developed in the performance of one task transfer to other tasks? The problem has really been conceived from three different angles: the influences of muscular activities on one another, the mutual influence of mental activities, and the cross effects, i.e., mental on muscular and muscular on mental fatigue. Between any two muscular operations the transfer has been found to depend upon their widespreadness. For example, the continuous exercise of the muscles of one hand and arm shows almost no transfer to the performance of the other arm, but has considerable effect on subsequent activities of the same arm. Action involving strenuous use of all the skeletal muscles affects almost any subsequent muscular activity. This is not strange because many identical elements are involved. Some slight transfer of fatigue from any muscular process would be expected from the known fact that the toxic substances from fatigued muscle are circulated through the blood stream.

It is more difficult to quantify the amount of transfer between mental processes because it is difficult to isolate particular functions. Practically any mental task involves the cooperation of all the mental functions. Studies of the quantitative effect of fatigue developed in mental multiplication, for example, on the ability to learn nonsense syllables, tell very little about transfer between separate mechanisms. For instance, Arai found that 9.4 hours of mental multiplication caused a 21.4% increase in time taken to memorize words. Her group of subjects after two hours of mental multiplication showed a 13.5% decrease in ability to memorize nonsense syllables. On the other hand, addition and free association were practically unaffected. Arai reports a direct proportion between the degree of fatigue developed in the particular operation and the amount of transferred fatigue.

Chapman had subjects work alternately in one-half minute periods on two tasks, adding and cancellation. Two control conditions were run, one in which the subjects alternated with rest every one-half minute, instead of working on the opposite task, and the other in which they worked continuously on one task. The greatest fatigue transfer between successive half-minutes occurred in the continuous condition; the least in the case of alternating rests; while the change of task caused a degree of fatigue transfer about half way between these extremes. The difficulty with these studies is that we have no quantitative gauge of the number of common elements in the two tasks. In order to give an adequate answer to the problem, Bills and McTeer formulated the tentative hypothesis that fatigue transfer is proportional to the number of identical elements in any two tasks. They chose a group of tasks in which the number of common elements was quantifiable, that of writing letter sequences. One task always consisted of writing ABC continuously. The other tasks differed in the number of letters they contained which were identical with these. Thus, ABD has two identical elements, AEF has one and EFG has none. The results show that the amount of transferred fatigue is roughly proportional to the number of common letters in the two tasks. This principle suggests the corresponding principle of similarity which has been found successful in explaining transfer in learning.

The influence of physical fatigue upon subsequent mental performance was studied by Dockeray. In 1915 he reported the results of experiments in which physical fatigue induced by gymnastic exercises involving the musculature of the whole body, and by the isolated exercise of particular muscle groups, was followed by mental work of five types. These were an addition test, a multiplication test, a simple attention test involving reaction to a sounder and an association test involving the memorization of ten pairs of nonsense syllables. Dockeray found the effects of the physical fatigue on the addition and multiplication to be very irregular. A subject might do better after the physical fatigue than after rest, or his speed might increase and his accuracy decrease. The results also depended on the amount of physical work done. One subject made a poor record after rest, improved after running 18 laps, and made a still better record after 27 and 36 laps. On the other hand, the sounder and association tests gave more stable results and showed in most cases a diminished efficiency after physical work. Fernberger found that where dynamometric or ergographic work was performed by the muscles used in the weight-lifting experiment, there was a marked influence on the correctness of the subject's judgment of lifted weights. The second weight was more likely to be overestimated and the interval of uncertainty was increased 30%.

The opposite relationship, that of the influence of mental on physical work, was investigated by Mosso. He found that the mental fatigue resulting from a period of strenuous thinking such as is involved in giving a lecture, or taking a two-hour examination, caused a marked change in the character of the ergographic curve of himself and his friend Dr. Maggiora. The duration was less and the height of the movements was reduced. Not only the voluntary curve, but also that obtained from electrical stimulation was lowered. Not all his subjects were thus affected, and other authors have found contradictory results. For example, Bolton found performance with the ergograph considerably increased after two hours of addition. The results with the dynamometer are even more inconsistent than those obtained with the ergograph, so that no final answer can be given to the question. Mosso's results have been criticized on the ground that delivery of a lecture requires considerable physical as well as mental work. The common elements theory of fatigue transfer would not fit these latter forms as well as it would cases of transfer between different mental operations or between muscular activities which bring into play common muscle groups. Mosso suggests that it can possibly be explained in terms of a fatigue product which is circulated throughout the system through the blood stream and affects all tissues. But in support of this he quotes experiments where the blood of fatigued animals was transferred to an unfatigued one and produced symptoms of fatigue. More recent work of a similar nature throws doubt on this sort of experiment. As far as the transfer of fatigue is concerned between operations in which entirely different muscle groups are used, the evidence is again contradictory. Lombard found that when one finger is fatigued, voluntary contraction of another finger will give as great a curve as before; but Ioteyko found that fatigue of the right hand decreased the power of the left hand.

A related question has arisen with reference to the performance of two operations simultaneously, as for example, squeezing a dynamometer with all one's might, and carrying on mental operations simultaneously, or squeezing a dynamometer with the right and left hand simultaneously. Lehmann reports that in the first case the dynamometer squeeze is reduced in strength in direct proportion to the intensity given to the mental operation. This might be interpreted as meaning that a common reservoir of energy is being drawn on in the two operations, so that increase in dissipation in one direction necessitates a compensatory decrease in the opposite direction, but contrary evidence is available. And regarding the second situation, that of a dynamometer squeezed with both hands simultaneously, evidence shows that the maximum squeeze of each hand is actually increased. No doubt there are common sources of the energy expressed in any activity of the organism; for example, the degree of voluntary effort. But there are also many sources of energy confined to the particular operation, so that the combined result involves no one-to-one relationship.

In connection with this topic no reference has been made to the innumerable studies on the changes in test efficiency at different periods of the day, which are assumed to be caused by transfer of fatigue developed in the mental operations carried on during the day. These have been adequately discussed by Thorndike in his treatment of mental work in the *Educational Psychology,* and they have very little significance for the problem of transfer, because of the lack of control of the day's work, and because, as Thorndike points out, there is a good deal of doubt as to whether any appreciable amount of fatigue was developed which could be transferred.

REST AND RECOVERY FROM FATIGUE

One of the chief problems that concerned the early work of Kraepelin's students was the influence of rest periods on the work curve. There are several related problems such as the rate of recovery from mental fatigue as compared with physical fatigue, the optimum distribution of rest periods both as to frequency and as to length, the position at which rests are introduced, and the difference due to different kinds of task.

The Curve of Recovery

The curve of recuperation for muscular work of the ergographic type has been plotted by Manzer. He plotted the curves for finger, hand, arm, leg, and trunk flexions. The subjects worked to exhaustion, then rested either five, or ten or twenty minutes, and then tested their degree of recovery. The average recovery after five minutes was 82%; after ten minutes, 90%; and after twenty minutes, 95%. In other words the curve of recovery from muscular work of this sort appears to be negatively accelerated with more than three-fourths of the recovery taking place during the first five minutes. After the twenty minute point the curve tends to become asymptotic to the initial unfatigued level. Small muscles he finds recover more rapidly than large ones. No published curves of recovery from mental work are available. Several obstacles stand in the way of a controlled experiment of this sort. Due to the unconscious adjustment of the subject to the mental work situation, he never puts forth his maximum effort continuously enough to produce exhaustion. Hence it would be necessary to use some relative rather than absolute zero for the origin of the recovery curve. The shape of the curve of recovery from partial exhaustion may be different from that for complete exhaustion. Another difficulty is that an individual's mental performance at a given instant is not as closely related to his maximum capacity at that instant as is the muscular output. A slight shift of incentive can cause a large shift in level of output. With these difficulties in mind, Bills performed the following experiment. A large group of subjects were asked to write a short letter sequence repeatedly to the speed of a metronome. The metronome was set at a rate which was as fast as the subject could possibly write for ten seconds. Starting at this rate, the subjects worked until they could no longer keep up. The speed was then reduced slightly and they again proceeded until another reduction was necessary, etc. When they were working at one half their original speed, or after about fifteen minutes, they were stopped and immediately tested for top speed for a ten-second stretch. The group was then divided into several subgroups each one of which was given a different period of rest before being retested. These intervals varied from ten seconds to five minutes. It was found that recovery was very rapid, the curve negatively accelerated, and complete recovery had taken place within three minutes.

Kraepelin's students have called attention to the influence of the subject's attitude during work and during rest on the rate of recuperation. For example, Graf found that the time necessary for recovery is a function of the affective tone of the subject during work, the amount of attentional strain, and of volitional effort put into the task. If the worker anticipates great fatigue, a longer rest is needed to raise his affective tone. When a subject works under an added incentive, will his increased output have to be compensated for by a proportionately longer time for recovery? Crawley's results on ergographic work of arm and leg are interesting in this connection. Subjects worked to exhaustion, then rested 2 or 4 minutes, then worked again to exhaustion. In one condition a screen prevented them from seeing their record; in another condition, the screen was removed during the first work period, which acted as an incentive, and resulted in more work being done. Crawley raised the question whether the extra work done because of the incentive would produce extra fatigue so that a correspondingly smaller output would appear in the ergogram following the rest. The results show that a reduced output always occurred, under these conditions, but the drop was not great enough to fully compensate, since the sum of the output in first and second periods together was always greater than in the case of the non-incentive condition. Crawley feels that, to be consistent with the law of conservation of energy, we cannot assume that the incentive actually enables the organism to do more work with less energy consumption. But we can at least assume that a properly motivated subject can work with less friction and hence accomplish more without a proportionally greater energy expenditure.

The subject's attitude during the rest is also important. Graf found that the resting worker's attitude toward the resumption of work undergoes a series of changes during the rest. For the first five to ten minutes the attitude is favorable to resumption, then there is a drop in readiness followed by an ultimate rise. The optimal rest must terminate at a high point in readiness. Zimmermann found that this depends on whether the worker knows the exact duration of the expected pause. There is a decided relaxation of will during rest and, if the subject knows when the pause will end, he prepares for it by regaining his readiness set. Otherwise he is caught in an inefficient attitude and requires time to readjust.

Distribution of Pauses

It is impossible to establish any general rule for the optimum distribution of rest pauses. To begin with it varies with the kind, difficulty, and length of the work. Graf found, for simple repetitive mental tasks, that the optimum length of rest was two minutes for one hour of work and five minutes for two hours; a longer pause proved detrimental. For a physical task, on the other hand, such as working at chest weights for eight consecutive hours, Shepherd found that college men required 16.6% of the total time for rests. A less monotonous or less difficult physical task might require less rest.

Another factor is the position at which the rest is introduced. Wyatt concludes on the basis of industrial fatigue studies, that it should be placed at the maximum height of the work curve. But in some curves this is at the very beginning. Graf finds that the most favorable position for a single rest is after the second third of the work period, whether this is one or two hours long. He finds that where two rest pauses are introduced with a two hour work period, their length should bear the ratio of two to four.

Still another factor is the number of rest periods introduced. As in learning, an inverse ratio exists between length and frequency of rests. Very frequent rests are detrimental especially when the work is of such a nature that it cannot be broken up into small units without destroying continuity.

Finally there is the problem of how the rest period is spent. Wyatt reports that when a fifteen minute rest was placed in the middle of two hours' work in addition, complete relaxation gave a gain in output of 9.3 per cent; uncontrolled rest gave 8.3 per cent; mild mental recreation gave 3.4 per cent and physical exercise (a walk) gave only 1.5 per cent. We have already referred to the study of Chapman in which a change from addition to cancellation gave half as much improvement in output over the continuous work condition as was given by absolute rest during alternate minutes. In an industrial situation, Miles and Skilbeck, by introducing a fifteen minute period of change of work twice a day, increased the output of one group of workers 14 per cent, which was actually a larger increase than was obtained from an equal amount of rest. And Wyatt obtained an increase of 7 to 12 per cent in output of an industrial group by letting them work on a different task during the latter half of morning and afternoon.

REFERENCES

Becker, F. C., and Olsen, O. Metabolism during mental work. *Skand. Arch. J. Physiol.*, 1914, 31, 81–197.

Benedict, F. G., and Benedict, C. G. The energy requirements of intense mental effort. *Science*, 1930, 71, 567.

Benedict, F. G., and Carpenter, B. S. Influence of mental work and muscular work on metabolism. *U. S. Dept. of Agr. Exper. Stat. Bull.*, No. 208, 1909.

Billings, M. L., and Shepard, J. F. The change in heart rate with attention. *Psychol. Rev.*, 1910, 17, 217–228.

Bills, A. G., and McTeer, W. Transfer of fatigue and identical elements. *J. Exper. Psychol.*, 1932, 15, 23–36.

Blonsky, P. P. Die Alkaleszenz des Speichels als Indikator für Intelligenz und Psychische Spannung. *Psychol. u. Med.*, 1929, 4.

Bolton, T. L. Ueber die Beziehung zwischen Ermudung Raumsinn der Haut und Muskelleistung. *Psychol. Arbeit.*, 1902, 5, 175–234.

Chapman, J. C. The effect of rapid changes of work on performance. *J. Exper. Psychol.*, 1917, 2, 165–170.

Crawley, S. L. An experimental investigation of recovery from work. *Arch. Psychol.*, 1925, 13, 5–66.

Day, M. E. Influence of mental activities on vascular processes. *J. Comp. Psychol.*, 1923, 3, 333–337.

Dockeray, F. The effects of physical fatigue on mental efficiency. *Kansas Univ. Sci. Bull.*, 1915, 9, 197–243.

Dodge, R. Mental work. A study in psychodynamics. *Psychol. Rev.*, 1913, 20, 1–42.

Fernberger, S. W. The influence of mental and physical work on the formation of judgements in lifted weight experiments. *J. Exper. Psychol.*, 1916, 1, 508–532.

Gerard, R. W. The two phases of heat production of nerve. *J. Physiol.*, 1927, 62, 349–363.

Gerard, R. W. Studies on nerve metabolism. *Amer. J. Physiol.*, 1927, 62, 381–404.

Graf, O. Rest pauses. *Kraepelin Psychol. Arbeiten.*, 1925, 7, 548; 8, 265; 9, 228; 9, 563.

Ioteyko, J. La fatigue. Paris. Flammaron, 1925, pp. 331.

Laird, D. A. Experiments on the physiological cost of noise. *J. Nat. Inst. Indus. Psychol.*, 1929, 4, 254–258.
Laird, D. A., and Wheeler, W., Jr. What it costs to lose sleep. *Indus. Psychol.*, 1926, 1, 694–696.
Larguier des Bancels, J. Essai de comparison sur les différentes méthodes proposée pour la mesure de la fatigue intellectuelle. *L'Année Psychol.*, 1898, 5, 190–201.
Lehmann, A. Die körperliche Ausserungen bei psychischer Zustände. 1900.
Lewin, K. Untersuchungen zur Händlungs und Affectpsychologie. *Psychol. Forsch.*, 1928, 10, 142–254.
Lombard, W. F. Reinforcement and inhibition of the normal knee-jerk. *Amer. J. Psychol.*, 1887, 1, p. 1.
Manzer, C. W. An experimental investigation of rest pauses. *Arch. Psychol.*, 1927, No. 90, pp. 1–84.
Miles, G. H., and Skilbeck, O. An experiment on change of work. *J. Nat. Inst. Indust. Psychol.*, 1923, 1, 236–239.
Mosso, A. Fatigue. N. P.: G. P. Putnam's Sons. 1918. Pp. 334.
Muscio, B. Feelingtone in industry. *Brit. J. Psychol.*, 1921, 12, 150–162.
Poffenberger, A. T. Effect of continuous work on output and feelings. *J. Appl. Psychol.*, 1928, 12, 459–467.
Shepherd, G. H. Effect of rest periods on production. *Personnel. J.*, 1928, 7, 186–202.
Shock, W. Mental performance and the acid base balance of the blood in normal individuals. *Proceedings of the Indiana Acad. Sci.*, 1930, v. 40.
Skaggs, E. B. Changes in pulse, breathing, and steadiness under conditions of startledness and excited expectancy. *J. Comp. Psychol.*, 1926, 6, 303–315.
Thorndike, E. L. Educational psychology. Vol. III. N. Y. Teacher's College, 1914, pp. 408.
Thorndike, E. L. Curve of work and the curve of satisfyingness. *J. Appl. Psychol.*, 1917, 1, 265–267.
Vaschide, N. Influence du travail intellectuel prolonge sur la vitesse du pouls. *L'année Psychol.*, 1897, 4, 356–368.
Wyatt, S. Monotony. *J. Nat. Inst. Indust. Psychol.*, 1924, 2, 24–30.
Wyatt, S. Rest pauses in industry. *Indust. Fatigue Res. Board.* Report No. 42, 1927.
Zimmermann, W. Ueber Arbeitsbereitschaft. *Kraepelin Psychol. Arbeiten*, 1925, 8, 414.

CHAPTER XXIV

PHYSIOLOGICAL FACTORS INFLUENCING EFFICIENCY

THE GENERAL level of performance and rate of fatigue of the worker is determined not only by the effect of the work upon itself but as well by factors extraneous to the work. Among these are (a) the physiological conditions, (b) the environmental influences, and (c) the motivational factors. Considerable attention has been devoted to the first two, but the last group has been until recently neglected because of the complexity of motivation and the difficulty of quantifying or holding motives constant.

PHYSIOLOGICAL CONDITIONS

THESE include the effect of drugs, of internal secretions, of food control, of insomnia, of ventilation, and of atmospheric conditions. Studies in these fields have usually been more concerned with the specific factor — the drug or the fasting — for its own sake than for its psychological significance. As a result it is possible to say *what* are the gross effects of tobacco or insomnia, for example, on mental performance, but we cannot say *how* these factors exert their effects because the physiological side is so poorly understood. We know that nitrous oxide causes mental dissociation, but we do not know how. And physiology cannot enlighten us. Does it cause brain anaemia, or what?

Another unsatisfactory thing about studies of this sort is that they are subject to the influence of a number of uncontrolled variables. So important are these that they deserve to be listed.

(1) *Attitudes and Motives.* Both the subject and experimenter are likely to have preconceived notions or prejudices about the influence of the factor. Few people have a neutral attitude toward tobacco, alcohol, coffee. As far as the subject is concerned, the disturbing effect of his attitude can be avoided by concealing the dose, but this has not always been done adequately. And some things cannot be concealed.

(2) *Suggestion.* A subject who is expecting a given effect will be likely to get it. Even a trained psychologist has reported mild intoxication on what he later found to be pure water. Here again concealing dosages is effective, but it is rather hard to conceal from a person that he has lost two nights' sleep or that he has fasted for twenty days.

(3) *Temporary and Permanent Effects.* The action of drugs or other factors depends on the length of time over which they operate. None of the studies get at the cumulative psychological effects of the factor investigated. An outstanding case showing the different effects of alcohol on an habitual user and on a teetotaler is the experiment of Dunlap, in which the latter subject was completely incapacitated for work by the same dose which acted as a beneficial influence on the former's performance. Another fact which has sometimes been overlooked is that the effects of a single dose of a drug vary with the time elapsing after it is administered before the mental work is performed. The effect is not instantaneous and may linger for hours. Should we not assume that the same is true of insomnia and other factors?

(4) *Strength of Agent.* Several factors make control of the strength of the experimental condition difficult. For example, in smoking, those who inhale or who continually puff take in more smoke. In the case of alcohol, the diluteness is important. And in all cases, the effects depend in part on immunities which the subject has built up against the agent.

(5) *Sampling Error.* Peculiarly susceptible to errors from insufficient testing are studies of physiological agents. On the one hand, the skills tested are not stabilized by practice, and

on the other hand, they do not give a wide enough sample of mental functions from which to draw general inferences. One reason for the necessity of considerable practice is to habituate the subject to the emotional disturbances of the strange apparatus, etc.

(6) *Correlation versus Cause.* It has often been forgotten, in interpreting studies, that correlation is insufficient proof of causation. For example, one author discovers that there is a higher percentage of failures in high school amongst boys who smoke and this is interpreted as evidence of the deleterious effect of tobacco on mental efficiency. But this condition might occur with no direct causal relationship between the two. For the term " smoker " is loaded by its relation to other terms which in turn may be causally connected with poor scholarship, such as "good mixer," or " loafer," or " fraternity man," etc.

With these reservations in mind, let us examine a few major studies in this field.

DRUGS

We have the most psychological data on alcohol and tobacco, though caffeine and strychnine have not been neglected. For other drugs, the data of physiologists must be relied upon mainly.

Alcohol

In general, a detrimental effect has been found, particularly on mental operations and on coördination of movements. Important differences, however, result from variations in size of dose, dilution, individual immunity, suggestion, immediate and delayed testing.

Rivers reviews the early studies on the ergograph in most of which there was reported an immediate increase in muscular output as shown by the total number of excursions, but a falling off in height. This stimulating effect he attributes to sensory stimulation and to the excitement caused by knowledge of the dose, since the amounts, from 5 to 20 c.c. were insufficient to give any effect in his own experiment. He concealed the alcohol dose by making it taste identical with a control dose with the result that only large amounts, 40 c.c., were effective, and these sometimes caused a decided increase in the ergograph and sometimes a decrease. Subjectively the work seems to be performed with greater ease, probably a sensory illusion induced by the drug.

On the mental side, however, Rivers corroborated Kraepelin's earlier finding that large doses of alcohol have both an immediate and long time detrimental effect. Operations such as addition, typewriting, learning by heart, mental multiplication of four place numbers, and the McDougall dotting hole test of attention were used.* That tremendous individual differences in immunity exist is shown by the fact that some individuals were unaffected by doses of 100 c.c.

McDougall and Smith, using the dotting hole test, obtained the following relation between size of dose and accuracy: —

Dose	Increase in Error (%)
10 c.c.	21
15 c.c.	42
20 c.c.	39
25 c.c.	113

They determined the effect of dilution by comparing 20 c.c. alcohol in 60 c.c. water versus an equal amount in 200 c.c. water. The former increased errors 160%, the latter only 22%.

Dodge and Benedict studied the action of alcohol on a large number of motor functions. They found a general depressant effect on all but the heart rate, the amount varying from a 46% decrease in the extent of the knee jerk to a 9% decrease in rate of voluntary tapping, resulting from doses of 30 and 45 c.c. The same authors found that memory and association were slightly impaired. Miles corroborated their results in two major investigations, finding quality as well as quantity of performance interfered with.

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* This last named test is widely used in psychology and merits a brief description. A revolving disc has a series of small round electric contact points arranged on its surface in a spiral, giving a series of concentric circles from the center to the extreme periphery of the disc. In front of the revolving disc is a shield with an aperture in it, and the subject is supplied with a stylus with which he is supposed to hit each contact point through the aperture as it passes by. The stylus is electrically connected with the disc so that every time he hits a contact point, it registers on a counterclock. His score is the total number of accurate contacts made.

A more recent study by Hollingworth shows the effect of varying the strength of the dose. He used 2.75% beer in two amounts, a dose of 40–55 c.c. alcohol, and one of 66–79 c.c. The results on seven different functions are given below:

FUNCTION	PER CENT LOSS WITH	
	40–55 c.c.	66–79 c.c.
Steadiness	68	241
Tapping	7	13
Coördination	6	10
Color Naming	2	7
Opposites	5	12
Adding	10	15
Pulse rate	— 8	— 10

The drug proves to be a depressant in every case except that of the accelerated pulse rate. This pulse acceleration agrees with Dodge and Benedict's results, and is probably symptomatic of organic resistance. The loss is always greater with the heavier dose.

On the biological side, the evidence is conflicting. Arlitt administered alcohol to rats daily for several months with their food, in doses ranging from $\frac{1}{2}$ to $2\frac{1}{4}$ c.c. Not only did it retard growth and cause sterility and death, but it caused the disintegration of previously acquired maze habits and retarded maze learning in the alcoholic rats and in their progeny for three generations. This finding has recently been corroborated by MacDowell and Vicari. They got a significant increase in the error and time records of the third generation of offspring from alcoholic rats in running a circular maze.

There is an error, however, in attributing all the accompaniments of alcoholism in human beings to the alcohol. They may be causes rather than effects of alcoholism.

Tobacco

Here the problem of concealing the dose so as to eliminate the effects of suggestion, prejudice and sensory stimulation is much more difficult. While no one has been completely successful, some, as Hull, have certainly dealt ingeniously with the problem. Another fact is that in the case of smoking there is a multiplicity of agents operating and no way of separating them. Usually nicotine is assumed to be the drug involved. But it must be proved that nicotine is actually present in the inhaled smoke to any extent. Bush has questioned this, and has emphasized the fact that many other chemicals are present in the smoke in fully as large quantities, as pyridine and carbon monoxide. But in addition to this chemical complexity, there is the act of smoking itself which is certainly stimulating psychologically. And there are the variations in size of dose between cigar, cigarette, and pipe smoking, between inhaling the smoke or not, etc.

In controlling the amount of the dose it is necessary that subjects who are habitual smokers should go on a restricted tobacco regime, which is in itself extremely disturbing. And there is the recognized development of tobacco tolerance by habitual users which would minimize the effects on them.

Early studies, as that of Lombard, agree pretty well in reporting a decrease in efficiency as far as physical effort on the ergograph is concerned. The effects of a single cigar are felt for an hour. And more recently Bates and others have demonstrated an invariable increase in systolic and diastolic blood pressure and acceleration of the pulse from a similar amount of smoking. But as to the mental effects, there is wide disagreement. For every author who reports a loss another can be found who reports a gain in efficiency. We can divide the studies into groups in terms of the degree of control exercised.

One group, of which Bush is an example, merely compared the average before-smoking and after-smoking performance on several days. No cognizance was taken of the fact that efficiency would be certain to vary between a first and second test period even without an intermediate smoke. He tested free and controlled associational processes of fifteen subjects and invariably found a loss.

Another group, of which Berry, Carver, and Fisher are typical, were careful to alternate the smoking and non-smoking days, and to use a constant hour of the day. Berry obtained a gain of eight per cent in speed of addition but used only one subject, himself. Carver used a variety of tests with his subjects: card sorting, arithmetic, operating an adding machine, giving opposites, dart throwing, steadiness, and billiard playing. He found an immediate lowering of accuracy in finely coördinated movements and in steadiness, while routine associations were not markedly affected. Fisher also found that his subjects lost steadiness, on smoking days, in a blindfold test involving tremor and body sway. The task was to stand and hold a stylus steady in a hole. But he got an increased efficiency in a continuous choice reaction test, both time and errors being reduced; while no consistent difference appeared in a number cancelling test.

None of the foregoing experimenters tried to conceal the fact of smoking from their subjects. Therefore all of their results are questionable on this ground. Rivers proved conclusively that the mere process of administering any drug is itself exciting enough to cause facilitation. Now there is apparently only one way of concealing the dose in smoking. And the same method also eliminates the factor of the stimulation received from the act of smoking. This method is to have the subject perform the act of smoking in both control and experimental conditions, but to breathe in no actual tobacco smoke in the control condition. The subject must be deceived. Only three experimenters, Froeberg, Hull, and Dorcus have attempted this. Froeberg, for the control condition, arranged the pipe so that the smoke was drawn through cotton wool, to filter it, but the method failed. Hence Froeberg's results, showing a large loss in muscular precision and steadiness, and smaller losses in memory span, and controlled association, are subject to the previous type of criticism. Hull used a vastly improved technique. He invented a pipe, heated by an electric coil. When blindfolded, the subjects were unable to tell whether they were breathing tobacco smoke through this, or slightly moistened hot air. Hull used eighteen subjects, half of them habitual smokers and the other half not, and had them smoke the control pipe and tobacco loaded pipe, on alternate days. They were always given one testing before, and three testings at various intervals after smoking, so that effects up to an hour or more could be studied. As a further precaution, Hull always held the pipe for the subject, and he always smoked in the room himself, on control days, so that the subject would smell the smoke. This is of doubtful value because Max Meyer has evidence to show that breathing someone else's smoke is almost equivalent to smoking oneself. The results of his tests on a large number of functions are given in detail below:

Per Cent Gain or Loss From Smoking

Pulse	+ 6.09	Memory Span	— 5.07
Tapping Speed	— 0.35	Addition	
Endurance	— 5.76	Speed	+ 1.04
Steadiness	— 42.12	Accuracy	— 5.55
Cancellation Speed	— 1.02	Reaction Time in Reading	+ 0.38
Calcellation Accuracy	— 7.09	Facility in Learning	— 4.42
		Learning Reaction Time	+ 2.31

These results are in the main consistent with previously quoted studies in that (a) the *pulse* is accelerated more for non-smokers than for habitual smokers; (b) the greatest loss is in *steadiness;* (c) *speed* of adding is slightly facilitated as are other association reaction times; while (d) *accuracy* is appreciably lowered in all cases. Wide individual differences and inconsistencies, of course, existed, and these are only lump results.

Dorcus tested only pulse and blood pressure, but his method brings out the relative importance of the subjective factors in smoking, as distinguished from the action of the drug itself. He used a testing period of 75 minutes divided into five fifteen minute periods. During the first, the subject rested; during the second he was hypnotized; then an unlighted cigarette in a holder was put in his mouth which he smoked; in the fourth period he smoked two real cigarettes; and in the last he again rested. On certain days, the real smoke preceded the imaginary one, as a control. Pulse and blood pressure were taken every three minutes throughout. Dorcus agrees with all other investigators in finding an acceleration of pulse and a blood pressure rise with actual smoking. But he found a slight rise following the imaginary smoke, which most certainly shows, either that the act of holding and puffing is alone enough to affect the pulse, or that suggestion is responsible for a part of the rise in real smoking. These studies are valuable because of the light they throw on all similar experimentation and the necessity for constantly controlling subjective factors in every experiment.

Caffeine, Strychnine, and Other Drugs. — The remaining drugs we can divide into two groups with regard to their mental effects, corresponding to the two classes into which they have been placed in accordance with their physiological action — the stimulants and the depressants. Caffeine and strychnine belong to the former while morphine is typical of the latter. It must be borne in mind that all of these drugs run through a typical cycle or course in their action from the moment they are administered until several hours after. For example, the stimulating effect of caffeine is rather slow in appearing, showing itself within an hour and lasting several hours, depending on the size of dose. There is apparently no subsequent phase in which it depresses efficiency below normal. Strychnine is similar except that its stimulating phase is often followed by a subsequent depression. Cocaine, on the other hand, has a strong immediate stimulating phase and is very soon followed by a profound depression which more than overbalances it; and the action of morphine rises very gradually to a maximum of stimulation, followed by a descent below normal where it remains for some time. These effects can be represented graphically, as shown in Figure 105.

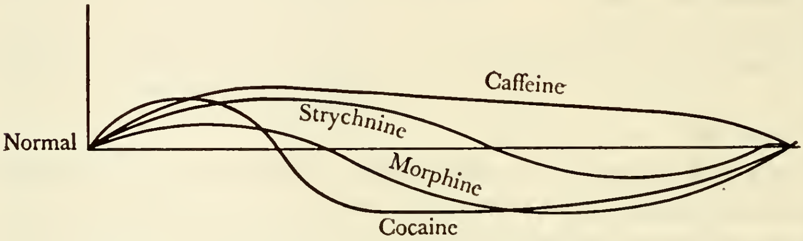


FIG. 105. Temporal action of different drugs

Hollingworth measured the influence of doses of caffeine, ranging from two to six grains, on sixteen subjects whose daily habits of work, food, and rest were carefully regulated. The experiment was extended over forty days and results from single doses were followed up with tests of mental and motor functions as long as seventy-two hours afterward. The drug was disguised by using a control dose and incentives were used to control motivation. The following points were established:

1. The effects appear within an hour and last from three to twenty-four hours. No subsequent depression was noted within seventy-two hours and no bad cumulative effects appeared in the forty days.
2. It causes loss of muscular steadiness and tremors especially with large doses.
3. The pulse is accelerated.
4. Speed and accuracy are increased as shown by tests of typewriting, color naming, opposites, addition, and cancellation, with all sized doses.
5. Sleep was seriously disturbed by large doses.

Strychnine is popularly supposed to stimulate intellectual processes. The evidence is conflicting. But much depends on the size of the dose and whether injected or fed through the stomach. Physiologists report that its action is mainly confined to the medulla and spinal cord, influencing the individual muscular reactions by lowering synaptic resistance. Early researches of Feré and of Jones on the ergograph are described by Rivers, showing an initial stimulation, followed by a diminution of muscular effort. More recently Poffenberger has worked with small doses of 1/30 to 1/20 grains taken internally with negligible results on motor speed and coördination, and on mental processes of discrimination, attention, and association. Pulse rate was decreased, while blood pressure rose. McDougall and Smith, on the other hand, using larger doses of 1/15 to 3/15 grains at intervals got striking effects. Errors in the dotting hole test were decreased 15%, and memory for lists of associated words was improved.

The same authors report that the effect of doses of opium (40 to 90 mm.) is slow in appearing, the maximum occurring

75 to 115 minutes after taking. There is a period of increased efficiency lasting 30 to 40 minutes, followed by a decline to a level below normal, which persists some time.

These various studies of drugs are sufficient to illustrate the difficulties involved, the techniques used and the procedures adopted. The facts as such have more practical than psychological significance.

INTERNAL SECRETIONS

The surprising thing about studies of the mental effects of disturbed gland functioning is that the central nervous system appears to be so well isolated physiologically. Profound changes in morphology and organic status under the action of internal secretions often leave the intelligence little, if any, affected. Most studies have to do with the learning function and have been discussed in connection with that topic.

DIET AND FASTING

The studies on the influence of fasting on mental performance illustrate well the difficulties encountered in achieving experimental control. To be satisfactory a study should bring out the effects both *during* and *after* the fast. Suggestion and prejudice should be eliminated by choosing naïve or disinterested subjects. The mental tests used should be highly practiced before the fast is entered on. The daily routine during the fast should be identical with the pre-fast regime except for the absence of eating. No experiment has met all these conditions.

Langfeld carried out a study on one subject, Agostino Levanzi, a lawyer who was personally interested in fasting as a therapeutic measure. He fasted thirty-one days, during which time he was tested eight times daily for muscular strength, sensory acuity, and mental performance. Langfeld reports a loss of muscular strength, a slight gain in sensory acuity, increased irritability, and a large gain in mental efficiency. But only three days of practice on the tests preceded the fast, and there was no adequate follow-up afterward, so that the gain may have been normal practice gain. And the subject was obviously prejudiced. His daily regime during the fast was entirely changed.

Marsh reports an experiment in which he and his wife acted as subjects. Instead of going without any food at all through the entire period, they gradually reduced the amount during the first week, took nothing during the second; and gradually increased their diet to normal during the third week. No adequate controls were run before or after. Tests were made daily of blood pressure, temperature and pulse, weight and strength, controlled association, sensory acuity, steadiness, and memory. The results show a fall in temperature and blood pressure, a loss of weight and strength proportional to food intake, and a slight slowing up of motor speed. The intellectual functions were affected but not consistently. The subjects' self observations indicate feelings of incapacity and discomfort. Marsh's conclusions regarding sex differences are valueless, based on two subjects, though they do bring out the presence of large individual differences. There is no support lent by this study to Langfeld's finding of

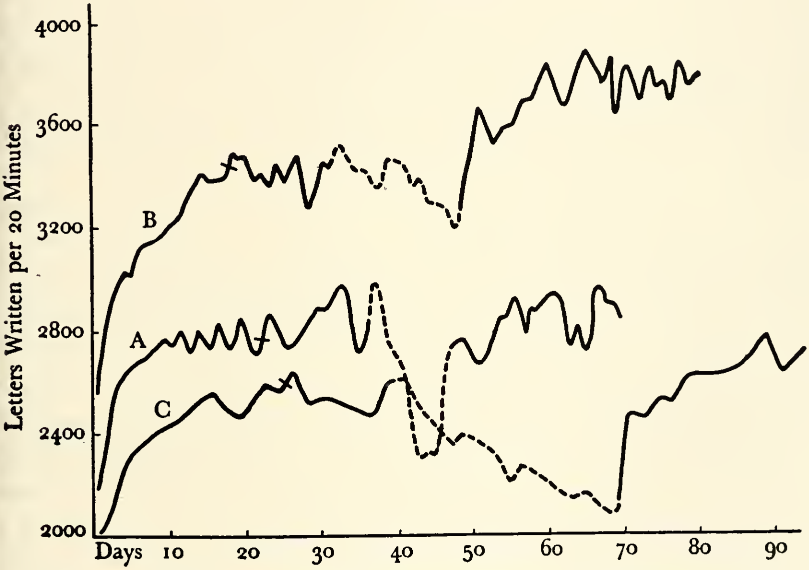


FIG. 106. Efficiency in mental work during fasting

From Glaze in Amer. J. Psychol., 1928, 40, p. 244, Fig. 2.

large improvement in intellectual functions. The interesting thing is that subjects feeling so upset can perform so normally on tests. But this is a universal observation in all studies on the influence of conditions. It suggests that our tests are not sensitive enough to differentiate.

Glaze performed the most carefully controlled psychological study of fasting. The only objection is that two of his three subjects were prejudiced in favor of fasts beforehand. One subject fasted ten, one seventeen and one thirty-three days. Long preliminary practice periods, thirty to forty days in length, and equally long post fast periods, were run, so that their total testing periods were respectively 77, 82, and 110 days. Tests of mental multiplication, color naming, backward writing, steadiness, visual acuity, etc., were given. The results bring out a decided practice effect in every test, showing that this undoubtedly accounted for Langfeld's results. But the practice curve is very irregular during the fast, usually showing a large loss. When the fast ends, there is a very rapid gain, which brings the level of performance considerably above the pre-fast level, and which exceeds any expected gain from practice. Fatigue is more rapid during the fast, and olfactory sensitivity is enhanced. A later study by Glaze of fasts lasting only a single day shows no consistent differences from the performance on ordinary days.

It may be concluded that only long fasts are effective and that these tend to produce muscular weakness, and somewhat diminished mental capacity while in progress, but an improvement above the normal, after the fast is over.

LOSS OF SLEEP

In addition to its practical significance the problem of insomnia has important theoretical aspects. Is sleep necessary to continued mental and physical efficiency? Outstanding cases exist of men who accomplish more than the average mental labor on a daily ration of sleep considerably below average. Is this merely an individual idiosyncrasy, or is sleep less indispensable than supposed? The question could be answered better if we knew just what sleep is physiologically. That it involves *rest* is obvious, but this is obtainable without sleep. That sleep is the most profound sort of mental rest is evident from the fact that consciousness ceases.

Physiological studies of sleep in animals, as dogs, show it to be essential to life. For example, Marie de Manaciene kept ten puppies awake artificially for several days (96–120 hours). Two of them died within a short time. All were dead within a week. Profound physiological changes occurred; temperature dropped several degrees below normal and red corpuscles decreased. A histological examination of the brain showed fatty degeneration of ganglion cells and capillary hemorrhages. Kleitman performed a similar experiment on dogs with analogous results. On human subjects, the physiological effects are not as well known. But the following results were brought out by a study of Kleitman and have been corroborated by others:

1. Changes in metabolism, as shown by decrease in respiration, heart rate, and blood pressure, and lowered temperature, though both Kleitman and Laslett report small changes in the latter.
2. No marked differences in blood count, blood or urine analysis, or body weight after as much as 115 hours insomnia.
3. No large alterations in sensory and motor functions, vision being unimpaired according to Gilbert and Patrick and Laslett; while the only motor functions which Lee and Kleitman found affected were the pupillary reflex and steadiness.

The first systematic investigation of the mental effects of insomnia was that of Patrick and Gilbert in 1897. They kept three subjects awake ninety hours and tested them every six hours on reaction time, memory for nonsense syllables and numbers, addition, and acuity. A few days of preliminary practice were given and used as standard. Vision improved but practice might account for it. One subject suffered hallucinations, a phenomenon frequently reported by subjects in other insomnia studies. The entire period of insomnia was rapidly compensated for by a moderate amount of sleep.

The study of Miss Smith performed in 1915 employed only one subject, herself, and therefore has little significance statistically, but its importance lies in the deviation of her findings from those of all other investigators. She practiced on the tests used in the study for several days prior to and following the experimental period. The insomnia period consisted of three nights of reduced sleep, 1½ hours the first, 3½ hours the second, and 5½ hours the third night. The five tests were: the McDougall dotting machine, memory for connected words, reversible perspective, typing, and nonsense syllable learning. The remarkable finding was that efficiency increased on the first day following the insomnia, and thereafter a period of subnormal efficiency appeared, lasting for two weeks. When the recovery period was broken into by another insomnia night, efficiency the following day was again high, with a subsequent prolonged slump. Miss Smith gives the facts a physiological interpretation in terms of the stimulating action of the fatigue toxins. This is possible but a more plausible explanation could be offered in terms of the heightened excitement with which she entered upon the day immediately following a sleepless night. Efficiency immediately following sleep is always lower because of the relaxed tonus which sleep causes.

Robinson contributed two important studies. In the first, he and Hermann tested three subjects on a series of daily tests of strength of grip, typing, aiming, reading letters of the alphabet, and mental multiplication, for thirteen to twenty-six days before and four to six days after the insomnia. The insomnia period was sixty-five hours. No objective effects were found. In a second study he and Mrs. Robinson used a group of twenty-five college students as an insomnia group over a twenty-four hour period of loss of sleep, and compared their practice gain on pre- and post-insomnia tests with a similar group of thirty-nine students who slept as usual. Three forms of the Army Alpha were given, one before the insomnia, one immediately after, and one after sleep had again been taken. The insomnia group improved slightly more than the controls, suggesting not only that insomnia was ineffective but that the experimental group were more highly motivated. They might have been overcompensating for a felt deficiency in capacity.

Lee and Kleitman, using a single male subject, subjected him to several periods of insomnia varying from 60 to 114 hours, and separated by long control periods. They found that the knee jerk, and the pupillary reflex were unaffected by the insomnia, but that the power to maintain standing equilibrium, as tested by the graphic records from the Romberg test, underwent marked deterioration. Sensory thresholds and mental efficiency were unaffected, except that sustained attention was impaired. This is shown by the increased time and errors in the long color naming task.

Laslett found that a reduced sleep ration, i.e., a forty per cent reduction in the amount of sleep for five consecutive nights, had a small but definite effect on the performance of four subjects in code writing, addition, the pursuit meter, the pursuit pendulum, and the ataxiagraph. There was a more profound effect on the Thorndike intelligence examination record, which amounts, in accordance with Laslett's doubtful method of computation (i.e., comparing their score with their college entrance score in the same test, and subtracting the estimated practice improvement), to about 14.9 per cent loss. Laslett ran a second experiment in which complete insomnia was maintained for seventy-two hours. Tests of visual acuity, speed and accuracy of eye movements, the Snellen letter chart, and the astigmatic chart were added to the tests previously mentioned. Effects of significant magnitude were found on the following tests:

Test	*Loss (%) in test period in comparison with three days immediately preceding*
Pulse Pressure	14.8
Code Test	10.7
Addition Test	13.8
Pursuit Meter	8.8
Ataxiameter: lateral posterior-anterior	33.8
Thorndike Test (Part I)	24.5

The other tests yielded negligible results.

In comparing the findings in these various sleep experiments certain things must be borne in mind. First, negative results should be scrutinized with suspicion. The tests chosen may not have been sensitive enough, or the subjects may have been motivated to over-compensate, or the tasks may not have been pursued long enough to really test the subject's ability to maintain a continuous attention. This is borne out by the many introspections in all these experiments showing a considerably depleted ability. For example, hallucinations were frequent, speech became tangled, sustained attention was impossible. Robinson stresses the irritability and lack of emotional control; and Kleitman reports that one of his subjects was unable to read or study, and couldn't take lecture notes, because his pencil kept dropping from his hand. In an experiment reported from George Washington University, one subject, required to drive a car, soon ran into the ditch on the left side of the road.

Evidently our tests of mental efficiency are inadequate. It is even probable that the whole group of experiments on the influence of physiological and other factors on mental output should be repeated with more sensitive or long continued tests. Perhaps, as Weiskotten suggested, inability to maintain sustained attention is the chief effect; and this might be perfectly compatible with unimpaired performance on very short tasks. The subject can, by supreme effort, rise to the occasion for a short time, but prolonged application is impossible.

ATMOSPHERIC CONDITIONS

This is a general class covering experiments which can be further grouped under three headings: (1) Weather, (2) Ventilation, and (3) Oxygen supply.

Weather

It is very difficult to determine to what degree the effect of weather conditions is actually physiological and to what extent it comes about indirectly through mood. That mood is greatly affected by all weather conditions is shown by Sullivan, who correlated her subject's self ratings of mood each day against the prevailing weather condition. A cheerful mood tended to prevail on bright, pleasant days, and various degrees of depression on dark disagreeable days. Yet a very low correlation was found between mood and performance in mental tasks, as addition, color naming and free association.

Bethel studied the effect of weather conditions on short periods of mental work. Five subjects were given a test of visual memory, the immediate and delayed recall of nonsense syllables; and a test of auditory memory, the immediate recall of numbers. The tests were given weekly, over a period of four months. The visual results were contradictory, but auditory memory was markedly affected. As relative humidity, barometric pressure, and temperature rise, the scores for auditory memory drop. Barometric pressure is the most important factor. These results are borne out in industrial studies of the British Fatigue Research Board, by Wyatt, Vernon, Weston, and others. Vernon found that a mean weekly outdoor temperature of 40–45 degrees gave about ten percent larger daily output than one of 60–65. And Weston reports a rise and fall of roughly one per cent in efficiency in the linen weaving industry for each degree rise or fall in wet bulb temperature.

Ventilation

This applies to the conditions of temperature, humidity, and recirculation of air in the room in which the individual works. The most extensive series of studies was carried out under the direction of Thorndike. He determined the effects of the foregoing factors on mental work: (a) when the subjects were urged to do their best, and (b) when they were left to their own choice as to whether they should do the mental work or loaf, or engage in activities of their own choosing. No differences in efficiency were noted in the first case between work done under extremely unfavorable conditions of ventilation (i.e., hot, humid, stale, and stagnant air of 86° Farenheit and 80% relative humidity), and work done under optimum conditions (i.e., 68 degrees F., 50% relative humidity, and 45 cubic feet per person per minute of outside air introduced). When temperature alone was varied, in the second case, between 75 degrees and 68 degrees F., no difference in inclination to work, or in the character of the output appeared; but with temperatures as high as 86 degrees F. and 80% relative humidity, there was a diminished inclination to work. Stecher studied the effects of humidity alone on four subjects by keeping temperature constant at 75 degrees F. Two conditions of humidity were used, 50% and 20%. The tests used included motor functions, as aiming, steadiness, tapping, and the reflex wink, and eyelid tremor and the mental functions employed in adding, typewriting and mirror tracing. No effects were evident either in subjective reports or in scores, over a period of two weeks. What the effects would be if the humidity had been varied in the opposite direction — toward wetness — is not evident, but judging from Weston's results, the effect should be detrimental. Again we have evidence of the adaptability of the human machine, and of the capacity of subjects to maintain a constant level of performance in spite of trying conditions, when adequately motivated.

Oxygen

The necessity of an adequate supply of oxygen to the brain for its operation has long been known. The supply already contained in the neurons is small and soon exhausted. Since the nerve impulse is electro-chemical and involves combustion, the nerves are unable to function without oxygen, and are subject to rapid asphyxiation. The question, then, is not *whether* oxygen is necessary but *how much* is necessary as a minimum supply, and what mental functions break down first? Due to the necessity for testing aviators for high altitude service in the World War, a tremendous impetus was given to experimentation on oxygen deprivation at that time. The result is that we now possess adequate techniques for this sort of study, and a body of carefully collected data. The oxygen supply is gradually reduced, either by controlling the supply by means of a diluting apparatus, or more commonly through the use of the Henderson rebreathing apparatus. In the latter case, the subject rebreathes the air from a supply tank which is thereby constantly depleted in oxygen content. Preliminary investigations of the psychological effects of low oxygen tension directed by Dunlap have been described by Bagby. The subjects were kept in the machine until they lost consciousness. Careful tests were repeatedly made of sensory acuity, motor control and performance, memory, attention, and emotional stability. Introspections and casual observations of both subject and experimenter were carefully kept.

Motor effects are tremor, incoördination, and overdischarge. Handwriting becomes large and illegible. Attention is affected by a decrease in distractibility so that the individual tends to perseverate in one direction. Hence simple mechanical tasks are better performed in the early stages, but in the advanced stages of asphyxiation attention completely disappears, so that commands must be repeatedly given in a loud voice. Emotional behavior is increased greatly in the final stages. The subject may become uncontrollably angry, breaking the apparatus, or silly, giving way to fits of laughing. Memory is affected in the later stage, so that the subject's introspections are totally ureliable, so that he may report afterward that he had perfect clarity to the end, even though his responses are completely disorganized for several moments before, thus disproving his statement. Recently an investigator reported that where subjects were given stimulus words to respond to by a finger movement, they later failed to remember the stimulus words even though they had responded at the time. This amnesia of fixation occurred for all stimuli immediately preceding the time when they reached asphyxiation. Lowson, in a recent experiment, used a chamber in which the oxygen supply could be systematically controlled, as well as the percentage of CO_2 present. In this way he could study the effect of specific amounts of reduction. The normal oxygen content is 21%. He used the following percentages: 19.1%, 17.8%, 13.6%, 11.1%, 10.1%, and 9.1%. No marked effects occurred till the oxygen supply was reduced 50% from normal. He found speed of movement least affected; accuracy fell off rapidly; and formation of associations was markedly affected, below 50% oxygen pressures. An analogies test, a same-opposites test, and a disarranged sentence test showed no great effects. He corroborated Bagby in finding that attention tended to perseverate, that the emotional threshold was lowered and that fatigue was much more rapid.

Summary of Physiological Conditions. — The most apparent finding in all these studies is not that the action of physiological factors is confined to specific functions; but that it requires sensitive tests to bring out the effects, and that some operations are, by their very nature, improved objectively even though the functions involved are impaired. Attention is usually rendered less flexible and less concentrated, a change which may benefit some operations and hinder others. Motor coördination and steadiness are affected while speed is relatively unaffected. Hence accuracy diminishes while rate of performance remains the same. Newly acquired or partially integrated habits are affected while old habits remain untouched, or may even be improved through the release of inhibitive attitudes. That which inhibits one operation may facilitate another by the same token. Our tests should test the underlying functions more directly, rather than the degree to which the objective output measures up to arbitrary standards of value whose significance is social rather than psychological or physiological. We need tests that will get at fundamental mechanisms.

REFERENCES

Arlitt, A. H. The effect of alcohol on the behavior of the white rat and its progeny. *Psychol. Monog.*, 1919, 115, p. 50.

Bagby, E. The psychologic effects of oxygen deprivation. *J. Comp. Psychol.*, 1921, 1, 97–113.

Bates, R. L. The effects of cigar and cigarette smoking on certain psychological and physiological functions. *J. Comp. Psychol.*, 1922, 2, 371–424.

Berry, C. S. Effects of smoking on adding. *Psychol. Bull.*, 1917, 14, 25–38.

Bethel, J. P. An experimental investigation of the influence of certain weather conditions upon short periods of mental work. *Amer. J. Psychol.*, 1925, 36, 102–112.

Bush, A. D. Tobacco smoking and mental efficiency. *N. Y. Med. J.*, 1914, 99, 519–527.

Carver, D. J. The immediate psychological effects of tobacco smoking. *J. Comp. Psychol.*, 1922, 2, 279–302.

De Manaceine, M. Sleep, its physiology, pathology, hygiene, and psychology. N. Y., Chas. Scribner's Sons, 1914, pp. 165–169.

Dodge, R., and Benedict, F. G. Psychological effects of alcohol. Washington. Carnegie Inst. of Wash., 1915, pp. 281.

Dorcus, R. M. Effects of suggestion and tobacco on pulse rate and blood pressure. *J. Exper. Psychol.*, 1925, 8, 297–309.

Dunlap, K. Effects of alcohol on hand and eye coördination. *Psychobiol.*, 1920, 2, 187–191.

Fisher, V. E. An experimental study of the effects of tobacco smoking on certain psycho-physical functions. *Comp. Psychol. Monog.*, 1927, 4, No. 19, pp. 50.

Froeberg, S. Effects of smoking on mental and motor efficiency. *J. Exper. Psychol.*, 1920, 3, 334–346.

Glaze, J. A. Psychological effects of fasting. *Amer. J. Psychol.*, 1928, 40, 236–253.

Hollingworth, H. L. Influence of caffeine on mental and motor efficiency. *Arch. Psychol.,* 1912, 22, pp. 166.

Hollingworth, H. L. The psychological influence of alcohol. *J. Abn. & Soc. Psychol.,* 1923, 18, 204–237. Also Part 2, 1924, 18, 311–333.

Hull, C. L. The influence of tobacco on mental and motor efficiency. *Psychol. Monog.,* 1924, 33, pp. 160.

Kleitman, N. The effects of prolonged sleeplessness in man. *Amer. J. Physiol.,* 1923, 66, 67–92.

Kraepelin, E. Münch. med. Wochenschrift, 1899, Jg. xlvi, S. 1365.

Langfeld, H. S. On the psycho-physiology of a prolonged fast. *Psychol. Monog.,* 1914, 16, pp. 50.

Laslett, H. R. Experiments on the effect of loss of sleep. *J. Exper. Psychol.,* 1928, 11, 370–396.

Lee, M. A. M., and Kleitman, N. Studies in the physiology of sleep. *Amer. J. Physiol.,* 1923, 67, 141–152.

Lombard, W. P. Some of the influences that affect the power of voluntary muscular contraction. *J. Physiol.,* 1892, 13, 1–58.

Lowson, J. P. The effects of deprivation of oxygen upon mental processes. *Brit. J. Psychol.,* 1923, 13, 417–434.

MacDowell, E. C., and Vicari, E. Alcoholism and the behavior of white rats. I. Influence of alcoholic grandparents upon maze behavior. *J. Exper. Zool.,* 1920, 33, 209–291.

McDougall, W., and Smith, M. Some experiments in learning and retention. *Brit. J. Psychol.,* 1920, 10, 199–210. Also, the effects of alcohol and some other drugs during normal and fatigued conditions. London: H. M. Stationary Office, Oxford Univ. Press. 1920.

Marsh, H. D. Individual and sex differences brought out by fasting. *Psychol. Rev.,* 1916, 23, 437–445.

Meyer, Max F. Alcohol, tobacco and tea; the efficiency under drugs as derived from the learning equation. *Amer. J. Psychol.,* 1923, 34, 501–510.

Miles, W. R. Alcohol and human efficiency. Washington: Carnegie Instit., 1924, p. 298.

Patrick, G. T. W., and Gilbert, J. A. On the effect of loss of sleep. *Psychol. Rev.,* 1896, 3, 469–483.

Poffenberger, A. T. The effects of strychnine on mental and motor efficiency. *Amer. J. Psychol.,* 1914, 25, 82–120.

Rivers, W. H. R. Influence of alcohol and other drugs on fatigue. London: E. Arnold. 1908, pp. 1–136.

Robinson, E. S., and Hermann, S. O. Effects of the loss of sleep. *J. Exper. Psychol.,* 1922, 5, 19–32.

Robinson, E. S., and Richardson, F. Effects of loss of sleep. II. *J. Exper. Psychol.,* 1922, 5, 93–100.

Smith, M. A contribution to the study of fatigue. *Brit. J. Psychol.,* 1915–17, 8, 327–350.

Stecher, L. I. Effects of humidity on nervousness and on general efficiency. *Arch. Psychol.,* 1916, No. 38, pp. 94.

Thorndike, E. L., McCall, W. A., and Chapman, J. C. Ventilation in relation to mental work. *Columbia Teach. College Contrib. to Ed.,* 1916, 78, pp. 1–83.

Vernon, H. M. Fatigue and efficiency in the iron and steel industry. *Rep. Indust. Fatigue Res. Board,* 1921, 5, No. 2.

Weiskotten, T. F. On the effects of loss of sleep. *J. Exper. Psychol.,* 1925, 8, 363–380.

Weston, H. C. An investigation into the linen weaving industry. *Rep. Indust. Fatigue Res. Board,* 1921, 4, No. 20.

CHAPTER XXV

ENVIRONMENTAL FACTORS INFLUENCING EFFICIENCY

MENTAL work always occurs in the presence of all sorts of stimulating conditions in the environmental background which are extraneous to the task itself and yet influence the efficiency of performance. The importance of these factors justifies the emphasis which the Gestalt school has placed on the " total situation." No adequate classification of these factors has been worked out which does not beg the question. For the same factor may at one time facilitate and at another inhibit activities in progress. For example, the term " distractions " implies that all extraneous stimuli, since they tend to draw the attention away from the task in hand, are inhibitive. Yet the opposite is often the case. In fact when one has become accustomed to working in the presence of certain extraneous stimuli — as mechanical noises — their removal proves more distracting than their presence. For convenience we will classify environmental factors into (A) Physical factors, and (B) Social factors.

PHYSICAL FACTORS

THESE may be subdivided into (a) so-called distractions, (b) music and rhythms, (c) color, brightness, and character of surroundings, (d) diurnal, weekly, and seasonal variations.

Distractions

In order to understand the action of extraneous stimuli in facilitating and inhibiting the performance of a certain act, it is necessary to reduce the situation to the simplest possible terms. The knee jerk set-up is as good as any. The question then reduces to the following terms:

If we designate the tendon blow which sets off the knee jerk as (S_1) and the knee jerk reflex itself as (R) then what will be the effect of any (S_2) delivered synchronously with (S_1) on the character of (R)? Presumably (R) might be affected in strength or in quickness. Within the limits of the simple situation, (S_2) might be delivered simultaneously with (S_1) or a very short time before or a very short time after. But, in the last case, no effect could be expected, because (R) occurs within a tenth of a second after (S_1) is delivered. In the other two cases, the effect might differ with the temporal relation of the stimuli. It might also differ with the relative strengths of the two stimuli. Enough study has been given to the problem so that a definite answer can be given. For example, Bowditch and Warren (1890) found the following effects on the knee jerk of varying the time interval between (S_1) and (S_2), where (S_2) is the clenching of the first and always precedes (S_1). See Figure 107.

It will be seen that if the blow on the knee follows the (S_2) at an interval not greater than 0.4 seconds, the result is to reinforce the knee jerk. If the interval exceeds this amount a diminution of the knee jerk results.

This effect is commonly accounted for neurologically by saying that, in the former case, the energy of (S_2) is drained into the S_1–R channel, whereas in the latter case the energy of (S_1) is drained into that response to which (S_2) is the normal stimulus. In the second case, we would say that (S_2) acted as a distractor.

A slightly more complicated situation is that of the reaction time experiment. Specifically, is the time of the simple reaction lengthened or shortened by stimuli given simultaneously, or just before? And what of the relative strength of the two stimuli? Todd (1912) using as stimuli, light, electric shock, and sound, found that the simultaneous reaction to two or more stimuli is less than to either of them presented alone, and that to three stimuli is still shorter. On the other hand, the reaction time to a light stimulus *preceded* by a sound and electric shock stimulus, is longer than the reaction time to the light alone. But a reduction of the time between the stimuli causes a reduction in the reaction time. The intervals used were 360, 180, 90, and 45 sigma. Probably a similar phenomenon accounts for Woodrow's finding that if the ready signal to a simple reaction occurs more than two seconds before the stimulus, the reaction is lengthened. In fact Woodrow used this technique as a method of measuring the degree of attention by introducing a distractor.

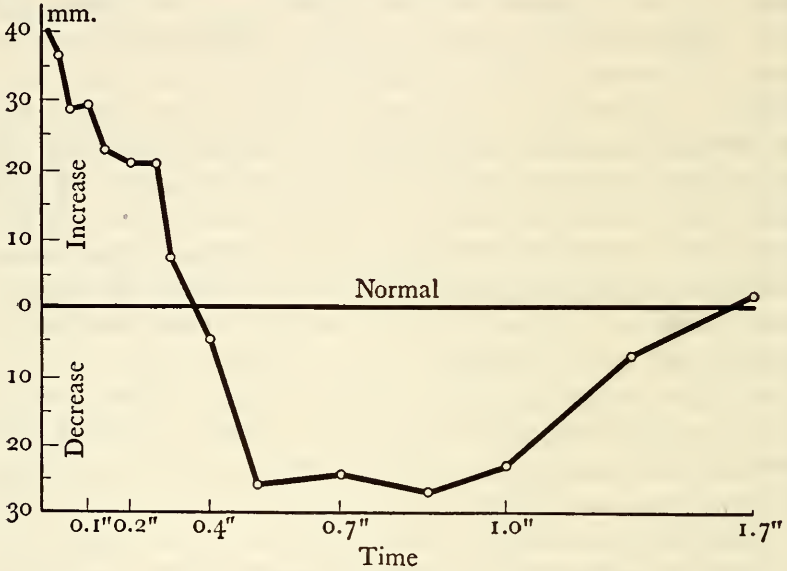


FIG. 107. Facilitation and inhibition in the knee jerk

From Bowditch and Warren in J. Physiol., 1890, 11, p. 38, Fig. 7.

Dallenbach and Cassel worked with both continuous and intermittent distractors, using auditory stimuli, a metronome, a bell, and a continuously driven tuning fork. They found that the distractor inhibited or facilitated the reaction depending on the time relations. The subject's attitude also influenced the result, as did the degree of habituation to the distractor. With enough habituation all effect disappeared. This corroborates Evans' finding that the effect of distractors may be removed by practice and this immunity may transfer to different reactions and to different stimuli. Dallenbach found the continuous distractor the easiest to adapt to and the intermittent the hardest.

Evans demonstrated that the greatest effect of a distractor occurs when it is of the same sensory modality as the stimulus proper. Thus an auditory distractor affects an auditory reaction more than a visual distractor. As to the relation between the absolute intensity of the distracting stimulus and the amount of facilitative effect on a simultaneous reaction, there is little evidence. But R. MacDougall measured the reaction times for two subjects to sound with varying intensities of visual stimulation, and obtained shorter reaction times with faint light than with bright light. Johnson found that reaction times to two spots projected on a circular test field varied with the brightness of the surrounding field, the shortest reaction times occurring when field and background were equal in strength. Apparently too strong an accessory stimulus draughts the energy from the reaction.

Many studies attest the strengthening of voluntary muscular efforts by simultaneous stimulations. Feré demonstrated that an increase in the dynamometer squeeze occurs when a strong visual or auditory or tactual stimulus accompanies the voluntary innervation, or when the subject is asked to engage in mental multiplication simultaneously.

However, the fact that isolated distracting stimuli are either facilitative or inhibitive to the speed or strength of reflexes and simple voluntary reactions does not answer the practical problem. We wish to know what effect continuous or intermittent stimuli will have upon a continuous mental performance. Both Geissler and Dallenbach had used auditory distractors in connection with visual discrimination in the former and auditory discrimination in the latter case. The results are characterized in Geissler's words, " the most complex combination of distractors after a few days' work was unable to induce great variation in attention. Instead, toward the end of the whole group, most of the normal series were actually performed at a slower rate than the distraction series."

Morgan (1916) attacked the problem from the point of view of energy expenditure. He raised the question whether, if an individual performs better under distraction, this extra output is gratuitous, or whether it actually requires an excess expenditure of energy which must ultimately be compensated for. He measured energy output in two ways, by registering the muscular tension of the subject in responding, and by noting overt vocalizations and other over-discharge. The mental work consisted of a code substitution test in which letter and number stimuli were exposed in scrambled order and the subject had to respond by pressing the corresponding keys on a key board. In this way muscular tension could be recorded by the amount of pressure on the key springs. Both speed and accuracy were computed. The distractors consisted of loud bells, buzzers, and phonograph records of both musical and humorous monologue. Morgan found that the distractors caused an initial retardation of speed followed by a return to normal and frequently to a rate superior to the normal. Effort, as shown by energy expenditure, increases considerably under distraction and he considers this more significant than rate increase, because the subjects apparently compensated for the distraction by increasing effort so as to maintain the normal standard of output. Hence the increased output is not attributed to summation of neural excitation nor to dynamo-genesis, but to over-compensation. His conclusion is that "any real or imagined change in the resistance offered to the maintenance of a set causes a change in the output of energy."

Recently Ford made an elaborate study of the influence of distracting stimuli in two forms: a Klaxon automobile horn placed about two feet from the subject's ear, and a phonograph with loud speaker close to the subject's head, playing records of humorous monologue. He chose, as his type of work, problems involving the selection and addition of single digit numbers from a row of mixed letters and numbers, the sums to be written on a strip of paper. Example: Gd 7 F c 8 N f E a W q, etc. The purpose of this was to prevent automatization so that attention could wander from the task. Ford considered that he had thereby corrected a defect of previous work on distraction. Record was kept of the pressure exerted by the subjects in writing; articulation was recorded pneumographically; and the vasomotor wave was registered by plethysmograph. Each sitting consisted of three periods: first, six problems worked in quiet, then six with distraction, then six with quiet again. The phonograph was tried in a preliminary experiment and abandoned. So the results are based chiefly on the automobile horn as distractor. The results, which include 183 sittings from 41 subjects, show that there is a prolonged initial reaction following either a change from quiet to noise or vice versa but that subsequent reactions are less affected. Ford attributes this to the automatization which sets in. That cessation of distracting noise is itself a distractor was shown in the subjects' introspections.

It is an interesting fact, however, that the last problem done under distraction is performed faster than any in the subsequent quiet period, though the latter had the benefit of more practice. This corroborates Morgan's finding that after the subject has recovered from the initial shock of the distraction. period, his efficiency actually exceeds that of the quiet period, and Morgan attributes this to the increased effort put forth. An examination of Ford's tension records shows a strong increase when distraction is introduced, then a drop, and then a rise to a maximum, as distraction goes on. The removal of the distractor brings a drop in tension. This also agrees with Morgan and we see no reason for Ford's interpretation of his results as contradicting Morgan. He thinks the improvement following the initial drop in output is due to automatization, and overlooks completely the increase in effort. In fact, by lumping together both quiet and distraction periods, he gets an inverse correlation of .55 between high tension and fast reaction, but if we take the distractor period by itself, this relation disappears. Hence we conclude that Ford's results corroborate Morgan's effort hypothesis.

From the preceding studies, particularly Morgan's, we can judge the rapidity with which the subject adapts or becomes habituated to distracting stimuli so that they become incorporated into the activity going on. This might be accomplished either by the automatization of the activity so that it ceases to demand concentrated attention, and hence is unaffected by distractors; or by habituation to the distractor so that it ceases to attract attention. To determine which is most important, one must be isolated at a time. Thus, to prevent habituation to the distractor, it must be variable and attention-compelling. Morgan found humorous dialogue more effective than mechanical noises for this reason. Intermittent and irregular noises are more effective than continuous noises. If, on the other hand, we desire to prevent automatization of the work task, we must choose an extremely variable one in which the set is constantly changing. Ford's task approached this ideal. Yet in both studies an initial inhibition was rapidly overcome.

Two recent studies have tested variable distraction in the performance of highly varied tasks. Hovey used, as his task, the Army Alpha Intelligence test. His subjects, college students, included an experimental group of 171 and a control group of 123. The distractors used were bells and buzzers, spotlights, phonographs, whistles, buzz saw, students performing stunts, etc. They were presented both simultaneously and successively. Two forms of the Alpha were taken. In the first sitting no distractors were used. In the second sitting they were presented to the experimental group only. The results show increases in the intelligence test scores of both groups in the second sitting due to practice. The average score of the experimental group increased from 127.5 ± 1.3 to 133.9 ± 1.2. That of the control group increased from 127.5 ± 1.3 to 137.6 ± 1.2. Hence the improvement under distraction was less than under quiet conditions, but not very strikingly so. There were no marked individual differences in susceptibility to distraction, nor was there any correlation with differences in intelligence nor with personality traits such as introversion-extraversion. This agrees with Tinker's findings on motor distractibility and intelligence.

On the physiological side, Laird reports a study of the effects of noise distractors of different intensities on the energy expenditure in calories of mental workers, as compared with their metabolism under the quiet condition of work. Typists were tested under two conditions; one in which there were other typists and people talking in the room; the other in which they were alone, and noises were shut out with noise-proof walls. The subject wore a respirator while working and the gas thus collected was analyzed to determine the respiratory quotient. There was a twenty per cent greater increase in the working metabolism over the resting metabolism of the subject when working under distraction than when working in quiet surroundings for two hours. Laird also reports a study showing the effect of sudden unexpected noises on the action of the stomach. Four individuals, equipped with stomach balloons, were subjected to ten minutes of noise, of 80 decibels strength, following a twenty-minute quiet record. The noisy period was followed by ten minutes of quiet. The kymographic records of the stomach contractions show a decrease of 37% in the number of contractions per minute caused by the noise. The subsequent quiet period shows an increase in rate and violence of contractions over the normal. This offers a sample of what is going on in the body during distraction. No doubt habituation would considerably lessen the effect.

Music and Rhythms. — Certain kinds of continuous extraneous stimuli have been found decidedly facilitative. Music has been studied from this angle. But it involves at least four elements which should be separately dealt with, i.e., sound as such, rhythm, affectivity and meaning. Any one of these may explain the total effect. Two books describing the effects of music on behavior are those of Charles Diserens and Max Schoen.

One of the earliest studies employing music as a distractor was that of Darlington and Talbot in 1898. They studied the effect of a phrase of music on the judgment of lifted weights, and concluded that it facilitated attention and had a general dynamogenic effect. Diserens studied the effect of phonograph music, slow and fast, on the onset of fatigue, on the speed, accuracy and extent of voluntary movement, and on certain vital functions. The results show considerable contradiction. Thus fatigue from continuous dynamometer squeezing was delayed and the strength of response facilitated. That from intermittent ergographic work was increased, the rhythm of the music seeming to interfere with the task. Accuracy in typing and handwriting from copy was decreased, but speed was increased. The extent of voluntary movements was increased and breathing became deeper. Pressure records obtained of the subjects while writing showed an increase in tension, while music was going on. These results as well as those of Gatewood on the effect of music on the efficiency of draughtsmen might result from the affective tone imparted or from the rhythm, rather than the tonal stimuli as such.

A study of Hyde brings out the effect of music of different sorts on electrocardiographic records and on blood pressure. She chose, as subjects, (1) persons fond of music, (2) those indifferent to it, (3) some Indians, (4) neurasthenics, and (5) animals. In general, it made a difference whether the music was familiar or not, and whether sung or played. Persons not susceptible to music were unaffected, while those fond of it showed a depressant effect from Tchaikowski's funeral march; a raised tonus from the Toreador song and the National Emblem March; and a steadying effect from lullaby records. The Indians were affected only by war dances. This might be taken to mean that the differential effect was largely through arousal of meaning, were it not for the fact that the dogs were similarly affected.

Extraneous rhythms have been found to aid work when the rhythms are timed right. On the other hand when they are out of time with the work rhythm, they are detrimental. The explanation probably goes back to the time relations between stimuli as brought out in the knee-jerk experiment of Bowditch and Warren. Ermanski points out that rhythm furnishes the basis for a rational organization of work. It saves by equalizing the work units; a rapid automatization follows rhythmic work due to the elimination of interfering tendencies. Effort is equalized and controlled, and the separate part processes are reinforced thereby. Sachsenberg studied the effect of rhythmic and anti-rhythmic stimuli on work efficiency and on fatigue. Five subjects were trained to perform a series of rhythmic movements, which were repeated at intervals, with either rhythmic or anti-rhythmic accompaniment. He found that the entire character of the movements, as photographically recorded, was affected; that an anti-rhythmic accompaniment increases weariness; that synchronized rhythm decreases it; and that practice reduces the influence of all rhythms. Düker found that when an arbitrary rhythm fits the subject's "natural" rhythm it increases quality and speed of output; otherwise it is detrimental. The rhythmic work takes less effort. He had three subjects work ten minutes daily for sixteen days adding figures and making paper bows according to a pattern. Two conditions were used; in one the subject worked according to his own rhythm; in the other he followed a definite tempo set by a sound hammer.

Color and Brightness of Surroundings. — The visual surroundings constitute another important class of extraneous stimuli. They may act as facilitators or inhibitors. For example, Pressy experimented with various shades of illumination of the room in which his subjects worked, using blue, green, and red. In another series he varied the brightness with hue constant. The mental task consisted of about fifteen minutes' work under each different hue, during which time he tested tapping rate, multiplication, judgmental reactions, free association, immediate memory, and a continuous choice reaction. No differences in output could be found with different hues, but a very definite relation appeared with brightness. In three of the tests, tapping, multiplication, and continuous reaction, there was a decrease of function under dim, and an increase under bright, light. McDougall and others had previously reported that there was no specific effect of either hue or brightness on reaction time. Feré had found that hysterics responded to red light with an increased strength in dynamometer squeezing, but it is doubtful whether this result would have been verified on normal subjects.

Johnson found that subjects sort cards by touch better when working in a good light than when working in darkness, even when visual cues to sorting are absent. Atkins, reviewing the literature, points out that all results show an increased efficiency in mental work with increased illumination up to 20 F.C. Burtt, on the other hand, tested the reaction times and the attention to tachistoscopically exposed stimuli, of subjects working under uniform and non-uniform conditions of illumination. In the non-uniform condition, a series of light and shadow areas played across the subject's field of vision. This type of lighting proved superior to the control. A similar advantage appeared with a constant dimming of the surrounding illumination. We can only interpret the results in terms of some facilitative effect exerted on the subject's attention by the variable illumination.

Another important problem is the optimal ratio between the brightness of the field and that of the surrounding background, for efficient mental work on visual material. Atkins found that a brightness of 37 ml. gave the greatest efficiency with black surroundings, while, with white surroundings, all intensities gave equal efficiency but only the lowest brightness was comfortable. Johnson, however, reports that for speed of reaction time the best ratio between brightness of surroundings and that of field is .75, where the field is slightly less, and any increase or decrease in the ratio causes a proportional drop in performance.

Diurnal, Weekly, and Seasonal Variations

A considerable amount of study has been devoted to the problem of temporal fluctuations in efficiency. The question is complicated in many respects. We might assume that in dealing with purely temporal variations we had isolated this variable. But the diurnal curve is tied up with the curve of cumulative fatigue. It is also largely a function of people's habits, and the diurnal habits of a student are quite different from those of a business man. The student usually does his heavy mental work late at night. Hence his curve at night rises at a point where the other's would fall. It is likely that there is no typical diurnal curve, even for a given person, but a different one for each kind of activity. Again, the seasonal curve is complicated by extraneous factors, such as temperature and humidity as they affect dress; work habits as influenced by holidays; completion of units of work such as semesters, etc. And the weekly curve is probably purely a product of the particular habits of the social group. In Russia, where Sunday is abolished, the weekly curve is doubtless entirely different. Rises and drops in motivation exert a tremendous influence. Hence we must not think of the time variable as in any sense a unit variable. It represents an extremely rough lumping together of a host of variables. It is not strange that the data are contradictory.

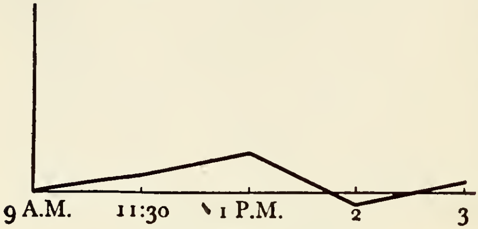
Diurnal Curves. The results depend on whether the subjects were school children as in the studies of Gates, Winch, Peaks, Dawson, and Stainer; or adult students as in those of Hollingworth, Marsh, Laird, and English; or industrial workers, as with Muscio, Vernon, and many others. We will present the curves of Gates for school children. They are not contradicted by any except Dawson's, which were practically flat throughout the day, but the only mental task he used was multiplication. And Winch only compared two periods of the day, morning and afternoon, which is insufficient data on the basis of which to construct a curve.

Gates (1916), using sixth grade pupils, averaging 11 to 12 years of age, as subjects, obtained records of their mental performance at each hour during the school day, from 9 A.M. to 3 P.M. Each class tested contained about forty pupils, and these were divided into five squads, so that a different squad was tested for each different hour of a given day. If squad one was tested at 9 on Day 1, it was tested at 10 on Day 2, etc., so that in five days every squad had been tested on all the tests at each hour of the day. The tests covered a wide range of functions, but on the basis of the results, we are justified in grouping the tasks into three major classes: (1) One class included addition, multiplication and completion; all of which involve *controlled association.* (2) A second group included auditory and visual memory and recognition, and hence tested *memory.* (3) The third group involved cancellation and speed and accuracy of movement in tracing. They are distinctly *motor tests.* Each of these three major functions gave distinct diurnal curves.

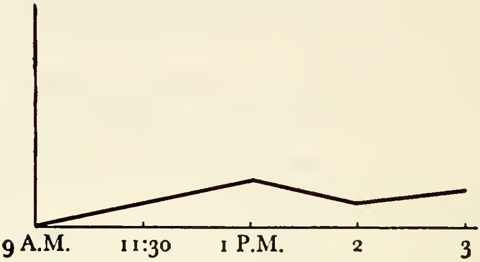
The controlled association group shows a gradual rise during the forenoon to 11:30, then a drop immediately after lunch, and a rise from 2:00 until 3:00 o'clock. The maximum is found between 11 and 12 o'clock, and the minimum at 9 A.M.

The memory group shows the forenoon rise, the after dinner drop and the subsequent afternoon rise; but in this case the drop after lunch brings the level of the curve below the morning level.

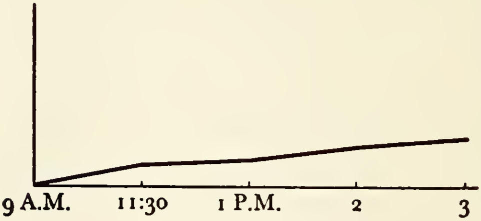
The motor group shows a steady rise from 9 o'clock in the morning right through the day to a maximum at 3 P.M. No drop occurs after lunch. Now when accuracy is separated from speed, it shows a drop in the afternoon, whereas speed shows a decided rise. But since the score used in the curve is a combined speed accuracy score, obtained by penalizing speed for each error by a constant amount, the accuracy drop is concealed.



MEMORY GROUP



CONTROLLED ASS'N GROUP



MOTOR GROUP

Fig. 108. Diurnal efficiency

From Gates in Univ. of California Publications, 1916, 2, p. 98, Fig. 5.

The work on the diurnal curve for adult subjects was brought together by Marsh up to 1906. His report covers the physical and physiological as well as the mental performance trend. His results on association, memory, and reaction time tests agree roughly with those of Gates, that is, a low initial level, then a rise to noon, followed by a slump and then a rise in the afternoon. His curves are carried beyond Gates' into the evening. The late performance shows a drop in the main. On the other hand physical strength as tested, for example, by the dynamometer grip, tends, like speed of movement, to steadily increase throughout the day to late afternoon, after which it declines. The physiological functions tested were heart rate, blood pressure, temperature and breathing rate, all of which increase during the day, from an early morning minimum. Recently Travis obtained measures of muscular tonus at regular intervals from the hour of rising in the morning to the retiring hour at night. Tonus is at its minimum on rising and increases throughout the day to ten o'clock at night. Functions like accuracy and height of attention, on the other hand, steadily drop.

A comparison of Marsh's work with other studies on adults, like those of Hollingworth and Laird, discloses some discrepancies. Hollingworth publishes diurnal curves for performance of five women and ten men in calculation, opposites, coördination and tapping. The former, which are intellectual tasks, show a steady decrement from 7:45 A.M. to 5:30 P.M. The latter being motor functions, show a tendency to improve rapidly until noon, with a slight drop thereafter which, however, never attains the initial level. Laird also, in his study on college students, found that the ability to read, comprehend, and recall declined throughout the day from 8 A.M. to 5 P.M. A slight spurt from 8 P.M. to 10 P.M. is no doubt accounted for by the study habits of college students.

Weekly Curves. Laird obtained the average performance level of 112 college students for each day of the week. He used the following tests: comprehension (the Thorndike Intelligence Test, Part III), code substitution; reading; immediate and delayed memory for words and ideas; and addition. The resulting curves show the performance level for each day as a percentage of the average week's performance level which is considered 100%. The curves for each task are plotted separately, and considerable variation is shown with task. For example, the curve for comprehension reaches its maximum of 114 on Monday and falls thereafter to Sunday. The addition curve reaches a maximum on Tuesday and then declines steeply. The other tasks have their high point on Wednesday. The memory curves are lowest on Monday, while the others reach the minimum toward the end of the week. The widest fluctuation is that of the memory curves whose Monday low is 88 while the Wednesday high is 122. In Figure 109 is shown the average curve for all tasks.

It is probably a fairly representative weekly curve, at least for students. It is characterized by a rise to a peak in the middle of the week falling away to a low point at the week end. Industrial curves have the same general trend.

Seasonal Curves. Peaks has made an elaborate historical and experimental study of seasonal variation in mental output. The most striking characteristic is a depression during the winter months. Recently Stainer, working with English school children, practiced them in addition at regular intervals for an entire year. The practice curves show plateaus consistently during December, January, and February. Although the plateaus may be merely a function of the stage of practice reached, it is possible that they reflect an actual seasonal variation, and if so, they corroborate Peaks.

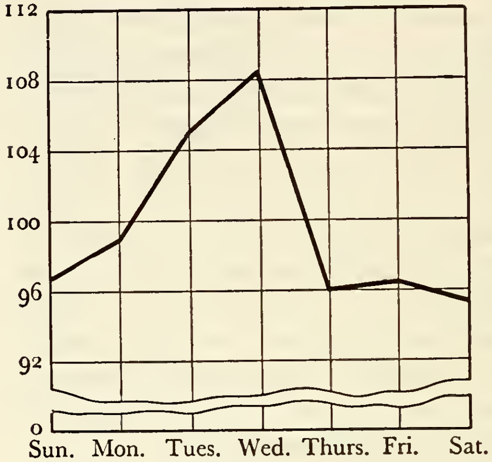


Fig. 109. Weekly variations in efficiency

From Laird in J. Exper. Psychol., 1925, 8, p. 57, Chart 4.

In industry, on the other hand, Vernon experimented with workers in a rolling mill, and found that their relative output was, in winter 102–124, in autumn 98–118, and in summer 88–111. This, it must be remembered, was for physical work, the seasonal variations of which may be independent from the other. Peaks attributes the yearly variations to temperature and strength of light, but admits that food, clothing, body temperature, humidity, and a host of other factors may have some effect.

SOCIAL FACTORS

In addition to the extraneous environmental stimuli of an inanimate or mechanical character, there is the social background in which mental work takes place. We must distinguish carefully between social factors which are and are not extraneous. For the moment we are interested only in the former. For example, if a subject finds his mental performance facilitated or inhibited by the presence of other human beings who are not competing with him nor judging his performance with reference to grading or rewarding or censuring him in any way, then we can describe the effect as due to extraneous social factors. But if rivalry or rating or competition enter in, then we are dealing with incentives and motives, which are not extraneous factors. Another point to keep in mind is this: it is difficult to distinguish between the purely mechanical aspects of social factors and the truly social aspects. If an audience disturbs a mental worker, and the disturbance is due merely to the noise made by the audience acting as a mechanical distractor, then this is indistinguishable psychologically from any other irregular auditory distractor. But if the disturbance which the mental worker reacts to is the fact of the presence of other human beings, i.e., if it is truly a social reaction, then it belongs under the category of extraneous social factors.

Allport is responsible for a pioneer study. Using twenty-six advanced university students as subjects, he tested their speed and quality of association under two conditions, (a) when working in solitude, and (b) when in the presence of a co-working but non-competitive group. Free chain association was used, i.e., the subject was given an initial stimulus word and then told to write down all the successive words that occurred to him. This caused too much writing, slowing down the association speed, so thereafter only every fourth word was written.

One experiment was run involving reasoning, the subjects being asked to write answers disproving each argument in passages from Epictetus and Marcus Aurelius. The results were scored for excellence and quantity. Allport found the group condition of work superior as regards speed of free association. The more mechanical process of writing was most benefited. Nervous subjects were adversely affected, while the slow subjects were the ones most benefited. The greater advantage came from co-working on the same rather than on opposite tasks. The group work was more variable than the solitary. As in the case of all other extraneous stimuli, the effect of the group tended to wear off with time. Certain qualitative differences appeared; the associations were less personal, shallower, and followed the initial stimulus better in the group. In the experiment on reasoning, the group condition speeded up the process but produced an inferior quality of argument and a lower level of association. The general conclusion is that the social situation promotes a greater quantity but an inferior quality of mental output. Allport's observation that nervous subjects are detrimentally affected by a co-working group has been corroborated by L. E. Travis in a study of free association in stutterers. Repeating Allport's conditions, he found that 80% of the stutterers produced more associations alone than in the group; whereas Allport found that 93% of the normals produced more in the groups. The average number of associations of all stutterers alone was 68.1 versus 65.8 for the group. Allport found 63.6 for the group, and 60.3 for the solitary condition, with normals.

In direct opposition to Allport's results are those of Dashiell. He made a comparative study of working alone; working with a co-working but non-competitive group; working in competition with others; and working under the close observation of spectators. Multiplication, analogies, and free association were the tasks. The co-working group had no influence. The spectators, however, caused an increased speed with decreased accuracy.

Apparently the *spectator* or audience problem is a different one from the co-worker situation. Gates found no significantly greater or less gain over the initial scores in a retest of college women when in the presence of an audience of six or thirty-seven observers, than when only the experimenter was present in the retest. Her tests consisted of coördination, color naming, analogies, and free association. Yet Travis found that individual scores in a task involving eye-hand coördination were considerably raised by the presence of an audience. Burri found either an attentive or inattentive audience detrimental to the recall of nonsense syllables which were learned alone. Apparently the discrepancy in the results is due to subtle differences in the attitude of the subjects toward the audience; though the character of the task may have some influence.

What is the effect of the presence or absence of the experimenter? Ichheiser reports an increase of 46% in the combined accuracy and speed of a group of subjects in putting together a block test due to the presence of the experimenter as a spectator. Yet in direct contradiction to this, Ekdahl found that the experimenter's presence was detrimental to the speed of his subjects in a free association test, the stimuli to which were given automatically. Not only were more responses given in the solitary condition, but the majority of his two hundred subjects preferred the solitary condition of work. The effect would no doubt depend on the personality of the experimenter and his habitual attitude toward his subjects.

Suggestion: — One of the ways in which the social relation expresses itself is through suggestion. Consequently, this factor becomes a variable in every human experiment. There are the suggestions which the subject receives from the experimenter, both intentional and unintentional. There are the suggestions from the stimulus situation, as in experiments with drugs. Practically any study of the influence of conditions illustrates the presence of the suggestion variable. In certain experiments it has been made explicit. For example, E. K. Strong studied the effects of suggestion on muscular activity. The activity consisted in squeezing a dynamometer with maximum grip. The suggestions were either positive or negative, as " Now you can make it stronger than usual," and were given visually or auditorially. They were given either by the experimenter or by the subject to himself. These conditions were compared with the neutral control condition. The results from only three subjects have little significance but the general tendency was toward a slight facilitation from all types of suggestion. Autosuggestion was most effective, but the benefit of the suggestion was never more than about a kilogram increase in the dynamometer squeeze. Suggestions delivered under the hypnotic trance are probably more effective than waking ones. Nicholson, using a Mosso ergograph for the task, studied the effect of suggestions delivered under hypnosis on the duration of the ergogram. In a control condition no suggestions were offered, although the subject was put in a trance. He reports a definite increase in muscular output from the suggestion.

It will be remembered that Dorcus found a slight effect of smoking an unlighted cigarette on the pulse rate and blood pressure of subjects in a tobacco smoking experiment.

REFERENCES

Allport, F. The influence of the group on association and thought. *J. Exper. Psychol.,* 1920, 3, 159–178.

Atkins, E. W. Efficiency of the eye under different intensities of illumination. *J. Comp. Psychol.,* 1927, 7, 1–12.

Bowditch, H. P., and Warren, J. W. The knee-jerk and its physiological modifications. *J. Physiol.,* 1890, 11, 25–64.

Burri, C. The influence of an audience upon recall. *J. Ed. Psychol.,* 1931, 22, 683–690.

Burtt, H. E. The effect of uniform and non-uniform illuminations upon attention and reaction time, with special reference to street illumination. *J. Exper. Psychol.,* 1916, 1, 155–182.

Dallenbach, K. M., and Cassell, E. E. The effect of auditory distraction upon the sensory reaction. *Amer. J. Psychol.,* 1918, 29, 129–143.

Darlington, L., and Talbot, E. B. A study of certain methods of distracting the attention. III. Distractions of musical sounds; the effect of pitch upon attention. *Amer. J. Psychol.,* 1898, 9, 332–345.

Dashiell, J. F. An experimental analysis of some group effects. *J. Abn. & Soc. Psychol.,* 1930, 25, 190–199.

Dawson, S. Variations in mental efficiency of children during school hours. *Brit. J. Psychol.,* 1924, 14, 362–369.

Diserens, C. M. The influence of music on behavior. Princeton. The Princeton Univ. Press, 1926, pp. 224.

Düker, H. Experimentelle Untersuchung ueber den Einfluss des Taktes auf fortlaufende Arbeit bei Kurzer Arbeitzeit. *Psychotechnische Zsch.,* 1930, 5, 82–86.

Ekdahl, A. G. The effect of attitude on free word association time. *Genet. Psychol. Monog.,* 1929, 5, 253–338.

Ermanski, J. Das problem des Arbeitsrhythm. *Prak. Psychol.,* 1923, 4, 165–174.

Evans, J. E. The effect of distraction on reaction time. *Arch. Psychol.,* 1916, No. 37, pp. 106.

Fere, C. S. Sensation et Mouvement. Paris: F. Alcan, 1899.

Ford, A. Attention-automatization: an investigation of the transitional nature of the mind. *Amer. J. Psychol.,* 1929, 41, 1–32.

Gates, A. I. Variations in efficiency during the day, together with practice effects, sex differences and correlations. *Univ. Calif. Publ. Psychol.,* 1916, 2, 1–156.

Gates, G. S. The effect of an audience upon performance. *J. Abn. & Soc. Psychol.,* 1924, 18, 334–342.

Gatewood, E. L. Music in an architectural drawing room. *J. Appl. Psychol.,* 1922, 5, 350–358.

Geissler, L. R. The measurement of attention. *Amer. J. Psychol.*, 1909, 20, 473–529.

Hollingworth, H. L. Variations in efficiency during the work day. *Psychol. Rev.*, 1914, 21, 473–491.

Hovey, H. B. Effects of general distraction on the higher thought process. *Amer. J. Psychol.*, 1928, 40, 585–591.

Hyde, Ida. Effect of music on electrocardiograms and blood pressure. *J. Exper. Psychol.*, 1924, 7, 213–224.

Ichheiser, G. Ueber die Veranderung der Leistungsbereitschaft durch das Bewustsein einen Zusehauer zu haben. *Psychotechnische Zeitsch.*, 1930, 5, 52–53.

Johnson, H. M. Speed, accuracy and constancy of response to visual stimuli as related to the distribution of brightness over the visual field. *J. Exper. Psychol.*, 1924, 7, 1–45.

Laird, D. A. Relative performance of college students as conditioned by time of day and day of week. *J. Exper. Psychol.*, 1925, 8, 50–63.

Laird, D. A. Experiments on the physiological cost of noise. *J. Nat. Inst. Indust. Psychol.*, 1929, 4, 254–258.

MacDougall, Robert. On the influence of varying intensities and qualities of visual stimulation upon the rapidity of reactions to auditory stimuli. *Amer. J. Physiol.*, 1903, 9, 116–121.

Marsh, H. D. The diurnal course of efficiency. N. Y. Science Press, 1906, pp. 99.

Morgan, J. J. B. Overcoming of distractions and other resistances. *Arch. Psychol.*, 1916, 35, p. 84.

Muscio, B. Feelingtone in industry. *Brit. J. Psychol.*, 1921, 12, 150–160.

Nicholson, N. C. Notes on muscular work during hypnosis. *Johns Hopkins Hospital Bull.*, 1920, 31, 89–91.

Peaks, A. G. Periodic variations in efficiency. *Educ. Psychol. Monog.*, 1921, 23, pp. 95.

Pressey, S. L. The influence of color on mental and motor efficiency. *Amer. J. Psychol.*, 1921, 32, 326–356.

Schoen, Max. The effects of music. N. Y.: Harcourt Brace, 1927, pp. 273.

Stainer, W. J. Rate of work in schools. *Brit. J. Psychol.*, 1929, 19, 439–451.

Stainer, W. J. A speed-accuracy competition. *Brit. J. Psychol.*, 1930, 20, 82–89.

Strong, E. K. The effect of various types of suggestion upon muscular activity. *Psychol. Rev.*, 1910, 18, 229–259.

Tinker, M. A. A study of the relation of distracted motor performance to performance in an intelligence test. *Amer. J. Psychol.*, 1922, 33, 578–583.

Todd, J. W. Reactions to multiple stimuli. *Arch. Psychol.*, 1912, No. 35.

Travis, L. E. The influence of the group upon the stutterer's speed in free association. *J. Abn. & Soc. Psychol.*, 1928, 23, 45–51.

Travis, R. C. A study in the measurement of muscle tonus and its relation to fatigue. *J. Exper. Psychol.*, 1924, 7, 201–212.

Travis, L. E. The effect of a small audience upon eye-hand coördination. *J. Abn. & Soc. Psychol.*, 1925, 20, 142–146.

Vernon, H. M. Report Indust. Fatigue Res. Board, 1921, 5, No. 2.

Whiting, H. F., and English, H. B. Fatigue tests and incentives. *J. Exper. Psychol.*, 1925, 8, 33–49.

Williams, G. W. The effect of hypnosis on muscular fatigue. *J. Abn. and Soc. Psychol.*, 1929, 24, 318–329.

Winch, W. H. Mental fatigue in day school children as measured by arithmetical reasoning. *Brit. J. Psychol.*, 1911, 4, 315–341.

Woodrow, H. The measurement of attention. *Psychol. Monog.*, 1914, 17, No. 76, pp. 158.

CHAPTER XXVI

INCENTIVES AND MOTIVES IN WORK

TYPES OF INCENTIVE

PROBABLY, of all the factors influencing performance, motivation is the most important. This variable can cause larger deviations than are caused by fatigue, or by most physiological agents. Yet it is almost impossible to experiment with motivation quantitatively because of the large subjective element which varies from time to time and from subject to subject. We have no assurance that because two objective incentives are equated the subjective effect is in any sense equal.

It is necessary to distinguish between incentives and motives. Motives are conative attitudes of the individual which predispose him to act in a certain way. These may be primary and simple as hunger or the desire for sex gratification; or they may be derived and complex, as the motive of social recognition which motivates a person to work for high grades in school, or to accumulate a fortune. On the other hand, incentives are the objective stimuli which satisfy the motivating condition, and which therefore stimulate the individual to behave in such a way as to secure them. In the case of a rat in a maze, the hunger is the motive, and the food is the incentive. With a human worker, hunger might be the motive, and a money reward the incentive.

In mental work, the stress has usually been placed on incentives, or incentive situations, and it has been tacitly assumed that the motive was present. Classifying studies of incentives roughly, we have the following types:

1. Competition and Rivalry
2. Knowledge of Results
3. Praise and Reproof
4. Encouragement and Discouragement
5. Positive and Negative Instruction
6. Specific Rewards
7. Specific Punishments or Threatened Punishments

Competition and Rivalry. Three situations can be differentiated: that in which the subject is one of a group which is competing with another group; that in which he is an individual competing with other individuals; and that in which he is competing against his own previous record. It is not necessary that one's competitors be present in person, since one can compete against absent or imaginary rivals. Moreover, the rivalry can be either intentional and made explicit by directions, or implicit in the situation.

The first type, individual rivalry, occurs in Triplett's report of studies of pace making (1898). There is an average difference in time between paced competition races and paced races against time of 5.15 seconds per mile up to twenty-five miles. And there is a difference between the speed of paced and unpaced races. Triplett's laboratory tasks of reel winding and counting aloud show a benefit, on the whole, both from the competitive situation on the former, and the pacemaking feature in the latter, in which the experimenter counted at a faster rate than the maximum unpaced rate of the subjects. There was an average gain of 6.6 per cent in counting due to the pace setting; all ten subjects were benefited. In the reel-winding competition there was a gain for 50 per cent of the subjects, no effect with 25 per cent and a loss with 25 per cent.

Another study of individual rivalry is that of Whittemore on twelve Harvard students. The task consisted of printing, with individual rubber types, paragraphs from a newspaper. Under one condition they were instructed to do as much as possible consistent with quality; under the other, to beat their fellow workers. All turned out more work when competing, the average gain being 26 per cent. The least capable subjects profited most. Quality of output, however, was detrimentally affected.

Of the second type, i.e., group competition, the study of Hurlock is an illustration. She tested 155 fourth and fifth grade children on addition forms chosen from the Courtis Research Test in arithmetic. Speed and accuracy were both required. The subjects were first divided into a control and a rivalry group, and the rivalry group was then subdivided into two sub-groups which competed against one another. On the fifth day the average gain in speed made by the control group was only .63 as against 3.93 for the rivalry group. The younger subjects gained more than the older, and the inferior ones gained more than the superior, from the rivalry. Contrary to Whittemore's results, accuracy improved 8 per cent.

Certain studies carried on by German investigators bring out the fact that group and competitive work lower the level of performance of the superior and raise that of the inferior members of the group.

Knowledge of Results. When a subject is informed of his past record and encouraged to surpass it, the knowledge acts as a spur to him. Arps obtained a long series of ergograms from three subjects working under two conditions, one in which they could observe their ergogram and one in which it was concealed. Both the absolute amount of work and the rate were greater, on the average, with knowledge. An early study of Wright in 1906 resulted similarly. Recently Crawley obtained ergograph curves of larger muscle groups, and found that more work was accomplished when the subject competed with a former record, and when his results were visible to him.

Praise and Reproof. Hurlock, working with 100 boys and girls from 9 to 12 years, engaged upon arithmetical problems, found that the boys improved most from reproof, while the girls showed the greatest gain under praise, and reacted adversely to reproof. In an earlier study she had found the effect of the two forms of incentive about equal as judged by performance on an intelligence test.

Encouragement and Discouragement. These were compared by Gates and Rissland, in a study of the effect of complimentary and disparaging remarks on performance. A group of college women were tested individually in speed of naming colors and tapping; then one third of them were complimented on their results, one third received adverse criticism, and to the remaining third nothing was said. Each subject then repeated the test. A slight gain resulted from either type of criticism, except in the case of the poorer performers, who were detrimentally influenced by disparagement.

Laird reports that both high school and college students respond better to positive incentives like encouragement than to negative incentives. He also found that college students, who were subjected to severe razzing, lost in steadiness and in speed of tapping.

Positive and Negative Instruction and Threat. Vaughn compared the effectiveness of direction to the subject stated positively and negatively, in shortening stopping time. The task involved a horizontal movement of the right hand along a track, the subject being told to stop when a red light was flashed. Negative instructions proved better than positive. Threat of punishment or of injury for long reaction times proved beneficial with both adults and children, but its effect was of short duration compared to actual punishment.

Specific Rewards and Punishments. The difficulty lies in attempting to devise suitable rewards and punishments which are dignified enough to administer to adults in a laboratory situation. Punishment studies have almost invariably used electric shock. Reward studies have been made either with children or in industrial situations. With animals, shock and food incentives are commonest.

Reward. An example is a recent study of Leuba's on children. He points out that it is unsafe to conclude that any one incentive is operating in a given experimental situation, and suggests a technique for isolating the effect of a given incentive. For example, to measure the effect of praise, it is insufficient to compare the output of a praised group with a control. One must find out how much subjects will exert themselves rather than do without the particular incentive. He therefore used a method similar to that for determining thresholds in psychophysics; i.e., he increased the requirement which the subjects must meet to get the reward, until no subject attained it; then decreased the requirement till everyone attained it. His measure of the stimulating value was, then, the average of the maximum outputs under conditions of increasing and decreasing requirements. His study on 35 eleven-year-old children, working on two-digit multiplication problems, in which chocolate bars constituted the incentive, makes it possible to compare the effect of reward alone, and in combination with other incentives. The simple incentive alone produced a 52% increase in level of output. When rivalry, praise and social recognition were added, the gain was 65%, or an additional 13%.

Kitson's industrial experiment with bonuses is typical. His problem was to find out how much a group of hand compositors in a Chicago printing establishment would improve their output under the stimulus of a cash bonus for extra productivity. The men had an average of ten years' experience; yet after five months under the new wage stimulus their output was improved 67 per cent.

Conflicting evidence exists as to whether the individual bonus or group bonus method is superior. For example, Maller tested about 1400 children for speed in simple computation, to compare the rate attained when working for personal interests, as for a prize, with that when working for a social unit, as for class victory. He found that the rate of work for the self motive was greater at first, and increased rapidly throughout the tests. Balderston, however, comparing the relative effectiveness of group bonus methods, where competitive groups are rewarded in terms of the performance of the group, versus individual methods of stimulation, found the group method superior for the majority, although very fast individuals tended to be held back. The apparent contradiction with Maller's results is probably due to the age of the subjects and the different degree of strength of the sense of group solidarity in the two cases.

Punishment studies have chiefly been made on the acquisition of new habits rather than on the operation of ready formed ones. Those of Rexroad, etc. were described in Chapter XII. The study of Vaughn on stopping time will serve as an illustration. In that study, actual punishment, delivered by means of an induction shock conducted to electrodes fastened on the subject's wrists, proved more successful than threat or warning with the majority of subjects. With some, however, strong shock completely destroyed their coördination, and was detrimental to efficiency. Crying and swearing gave evidence of the intensity of the emotional reaction which probably accounted for the disruptive effect.

Which is the stronger incentive, reward or punishment? The question is unanswerable until these two variables can be quantified. But if a reward can be found which is strong enough to counteract the severest practicable kind of punishment, then for practical purposes it may be considered the stronger. Knight and Remmers may be said to have set up such a situation. A group of college fraternity pledges were told that their election to a fraternity depended on their performance in certain tests. They were subjected to a severe hazing involving intense mental and physical strain throughout the period of testing, yet their performance was such that they solved twice as many problems in computation per minute as a control group of subjects who lacked the positive incentive.

Incidentally this last study illustrates the technique for quantifying incentives which is known as the constant obstacle technique. It has been used to quantify animal incentives. For example, if it is required to determine the relative strength of food or sex as incentives to a rat, the animal is separated from the incentive by an electrically charged grill of known intensity of current. The strength of the incentive is determined by the strength of current which will keep the rat from crossing the grill.

ATTITUDE AND SET

THE concept of set was discussed under attention. There is some question whether sets are definable in muscular terms or whether they involve purely neural configurations of central location. The fact remains that some sort of continuous control is exercised over mental operations in accordance with work sets, which operate without deliberate conscious effort and which may or may not have been dictated by the original task directions or "aufgabe." For example, a subject who is directed to give opposites will continue to do so, long after he has ceased to be conscious of any deliberate intention to respond to this particular direction. A series of figures may be presented, as $\begin{matrix}2, & 7, & 3,\\ 4 & 6 & 9\end{matrix}$ etc. The subject may be given a set to add or to subtract or to multiply the separate pairs. Once the set is established, it operates automatically and saves mental conflict. Besides these deliberate sets, there are various sets which are unconsciously assumed. For example, the speed at which a subject habitually works is usually maintained in spite of all sorts of obstacles. Any temporary tendency to drop below this rate is compensated for by extra exertion. Yet the subject may not realize the set under which he is working.

Several interesting problems present themselves. One is the problem of how speed and accuracy in work are affected when a subject is compelled to shift his set frequently. Another is the question of whether a speed or accuracy set developed in one work situation will carry over to other tasks so that it influences his speed or accuracy in the other task. This might be called "transfer of set." And a third problem is the manner in which a subject's work set is influenced by the amount of work he is faced with, or by the limit of time he has to work.

The first problem was studied by Jersild. He experimented with rapid shifts of set, the task consisting of alternate addition and multiplication of two place numbers. Eighty school children served as subjects. The loss due to the shifts decreased as the difficulty of the problems was increased. His conclusion is that well practiced functions suffer most from shift of set. His study of alternate naming of opposites and objects to a stimulus word, on thirty-four psychology students, brought out no loss from shift of set after the second trial. And when controlled association was alternated with addition, there was a gain instead of a loss. Also, in shifting from color naming to form naming to opposites to subtraction, speed was benefited. Twelve of eighteen subjects preferred the shifting task. This gain is therefore attributed to the break in monotony of the work. Finally, shifting from cancellation to adding gave a large loss. Jersild's conclusions are that shift of set does not invariably give loss of efficiency, but only where it introduces associative interference. Chapman, and Bills and Brown, found an advantage from less rapid shifts of task in addition and cancellation studies previously described. Evidently a shift of set, by removing monotony, is beneficial where it does not introduce competition among the elements, as was found by Robinson and Bills.

The second problem, that of transfer of sets, was studied by Cathcart and Dawson. They wished to determine whether the rate at which subjects performed simple repetitive movements would be changed by introducing an interpolated period of work on a similar task at a rate much slower or much faster than that at which the original task had been performed. Would the subsequent rate be deflected toward the intervening rate? Several forms of movement were used; working on an ergogram, tapping, dynamometer squeezing, and as complex a process as piano playing. In every case the interpolated rate persisted and affected the subsequent performance of the initial task. For example, in the tapping test, subject S showed the following effects:

NUMBER OF TAPS MADE IN FIVE SECONDS

Initial Rate	*Interpolated Rate*	*Final Rate*
11	23 (faster)	15
12	7 (slower)	10

Skilled musicians were affected in this way: for example, if a composition requiring a slow rhythm were followed by one calling for a rapid rate, the performer would susequently play the original slow piece at a more rapid rate, and vice versa.

The third problem under "set," that of the effect of the task with which the subject is confronted on his rate of work, was studied by Bills and Brown. This was designated the quantitative set. Two kinds are possible. A subject may be set to work a given length of time, regardless of the amount done; or he may be set to do a given amount of work regardless of the time taken. The former is a "time set," the latter an "amount set." The task consisted of continuous addition and the subjects were all advanced psychology students. For the amount set, they were given a definite number of examples to do and instructed to keep working till they were finished, working at all times as fast as they could with accuracy. Four different amounts were used: three lines, or 120 examples; six lines; twelve lines; and twenty-four lines.

For the time set, they were given plenty to keep them busy, and told to work as fast as possible consistent with accuracy, but no particular amount must be done. They were told they would be stopped after a certain definite time. Four time sets were used; two minutes, four minutes, eight minutes, and sixteen minutes. Under both sets signals were given each quarter minute so that rate could later be computed. The results show that a time set has no definite influence on a subject's rate of work, but that an amount set influences both the initial level and the amount of decrement which will develop. These results are shown in the table below.

Effect of the Amount Set on Initial Level and Decrement

Amount to be done	*Examples done in first Q.M.*	*Examples done per Q.M. in next three Q.M.s.*	*Decrement*
120 examples	19.2	15.7	3.5
240 examples	19.5	15.7	3.8
480 examples	20.0	15.9	4.1
960 examples	20.6	15.7	4.9

The conclusion is that the initial level and the decrement in work curves will vary directly as the amount of work with which the subject is confronted at the start. The same authors found that by breaking up a long task into a series of short tasks, the long task is performed at a higher level of efficiency than when presented as a whole at the beginning, even though the subject is given no rest between units. This is obviously due to the advantage gained by substituting the short-task set for the long-task set.

Mood. Among the kinds of attitude, an important class comprises the moods and emotional sets which the worker acquires. These are closely related to the problem of 'feelings of fatigue' which was discussed earlier. The evidence on the effect of moods is rather meagre. The difficulty in controlling such studies is that, to alter mood, one must change the work condition somehow; the resulting change in output may therefore be caused by the changed conditions of work, and not the changed mood. This is the fallacy in Mayo's study of revery and industrial fatigue. To counteract the worker's pessimistic revery, he introduced rest periods into the day's work. Efficiency was improved, as was also the character of the worker's day dreams. But the improved output may have resulted directly from the rests. Monotony is the great problem in most work situations. Thompson has devised a test of susceptibility to monotony which correlates .71 with independent ratings and personal history.

Other types of mood attitude which have been studied are the following:

Sullivan measured the effect of moods resulting from weather conditions. Efficiency is not affected.

Lewin and Hoppe studied the attitudes resulting from success and failure. Success raises, while failure lowers the subjects' standard of effort, in the majority of cases.

Vernon worked on the problem of group 'morale' as illustrated in the performance of a college rowing team. He concluded that attitude is more important than skill. Efficiency rises or falls with the level of group respect.

Menias reports studies on the influence on efficiency of excitement due to the arousal of mild emotional reactions.

The subject is an important one but requires greater control over the complex variables involved than can be secured in non-laboratory situations.

INTERRELATIONS OF SPEED AND ACCURACY

WITHOUT doubt efficiency in mental work is conditioned upon the fine adjustment between speed and accuracy. Is there an optimum rate of work for each individual and if so, what happens when this optimum is exceeded or when the rate falls below it? This is quite a different problem from that of the question as to whether fast workers are more or less efficient than slow workers. The latter question is one of individual differences to be answered later.

Bird, in an article called "The Devious Path of Slow Work," reports a study in which 100 college students were tested on slow and rapid addition of examples from the Courtis research tests. For two minutes they were required to work as quickly as possible, with a resulting average of three errors. They were then asked to continue adding, but to work slowly and cautiously. The average error score was five for the next two minutes. The deviation was not large. The inaccuracy of the slow work is attributed to mind wandering on the basis of the subjects' introspections.

A more adequate study is that of Garrett, which also contains a history of relevant earlier studies. Garrett sought to find the relation between accuracy and speed in three judgment situations; lifted weights, length of lines, and handwriting; and in two coördination tasks, maze tracing and thrusting a stylus into a hole. The results show (a) that there is an optimum rate for accuracy. In the judgment tests, accuracy increased gradually from the slowest rate used, 4 seconds, to a 2 second rate, after which it fell off regularly, the loss becoming more rapid between 1 second and $\frac{1}{2}$ second; (b) that the amount of loss in accuracy from increased speed is relatively very slight. An increase of 300 per cent in speed of weight lifting caused a change in accuracy of only ten percent; and an increase of 700 per cent in rate of exposure of lines resulted in only eight per cent decrease in accuracy; (c) that accuracy in the movement coördination experiments decreases much more rapidly with increased speed beyond a certain optimal point, but up to this point accuracy is helped by speed.

A related problem is that of whether speed or accuracy should be stressed in directing a mental or motor performance. Windmöller required 45 fourteen-year-old subjects to work on tasks such as typesetting, cancellation, addition, copying figures, cutting patterns, arranging cards and figures, etc. All tasks were performed under three different conditions: as fast as possible, as accurately as possible, and both at once. The results varied with the complexity of the task.

Emphasis on accuracy for simple tasks cuts down speed without changing accuracy. But complex tasks, requiring attention to details, benefit from accuracy instructions and stressing speed is detrimental.

Quite different is the problem of individual differences. Do fast individuals tend to be also accurate individuals? Or is the slow worker likely to be more accurate? The evidence is quite consistent. An early study of Thorndike's (1914), in which speed and accuracy in addition were compared, shows that the quick adder is more accurate than the slow adder. Among 671 students tested, the best 65 averaged 150 additions per 100 seconds, and made 7 errors per thousand additions. The 20 slowest averaged 37 additions, and made 17½ errors per thousand. Poppelreuter recently reported curves of distribution of the speed and accuracy scores of 100 subjects engaged in a tracing task. The subjects making the most errors were in the high speed end of the distribution, but the very slow subjects were scattered throughout, so that no correlation existed between slowness and accuracy.

Are there general speed and accuracy factors, so that a person who is quick or accurate in one task will be quick and accurate in other tasks? Hartmann obtained correlations of only about .20 between the precisions involved in any two tasks of sensory discrimination, or the accuracies in execution of any two perceptual tasks. With regard to speed, Dowd subjected 165 sixth grade children to a number of tasks involving cancellation, speed of movement, writing, reading, and arithmetic. The rates in the different tasks correlated from .13 to .87, most of them being low; so that she concludes that there is no general speed factor. Rounds, on the other hand, got correlations of .59 and .61 between speed in a battery of tests involving addition, completion, and figure cross-outs and the latent time of the Achilles tendon reflex.

Baxter attempted to differentiate individual temperaments on a basis of speed and accuracy. A few showed consistent quickness, along with consistent accuracy or inaccuracy, and others were consistently slow and accurate or slow and inaccurate. But the average tended toward no particular type.

In general, speed and intelligence have not been found to correlate highly.

Studies of individual and group differences in speed of mental work, accuracy, and susceptibility to fatigue have been made, but the discussion of them does not belong here. Garth and Klineberg have worked with racial differences; Kefauver has reported on differences in fatigability caused by difference in intelligence level in children, while Burnett and Wyatt have done the same for industrial workers. The relation of age to fatigability offers an extremely important problem. A study of Leiner on three age groups shows a decrease with increasing age between 10 and 17 years. Without doubt a reversal in the curve appears at some point beyond 30 years of age and a decided positive acceleration occurs in the advanced age levels.

REFERENCES

Arps, G. F. Work with vs work without knowledge of results. *Psychol. Monog.*, 1920, No. 125, pp. 41.

Balderston, C. C. Group incentives; some variations in the use of group bonus and gang piece work. (Res. Stud. No. 9) Phila., Univ. of Penn. Press, 1930.

Baxter, M. F. An experimental study of the differentiation of temperaments on the basis of rate and strength. *Amer. J. Psychol.*, 1927, 38, 59–96.

Bills, A. G., and Brown, C. The quantitative set. *J. Exper. Psychol.*, 1929, 12, 301–324.

Bird, G. E. The devious path of slow work. *J. Educ. Psychol.*, 1922, 13, 50–53.

Burnett, I. An experimental investigation of repetitive work. *J. Nat. Inst. Indust. Psychol.*, 1924, No. 2, 18–23.

Cathcart, E. P., and Dawson, S. Persistence, a characteristic of remembering. *Brit. J. Psychol.*, 1928, 18, 262–275.

Crawley, S. L. An experimental investigation of recovery from work. *Arch. Psychol.*, 1925, 13, 5–66.

Dowd, C. E. A study of the consistency of rate of work. *Arch. Psychol.*, 1926, 13, pp. 33.

Garrett, H. E. A study of the relation of accuracy to speed. *Arch. Psychol.*, 1922, 8, pp. 104.

Garth, T. R. Racial differences in mental fatigue. *J. Appl. Psychol.*, 1920, 4, 235–244.

Gates, G. S., and Rissland, L. Q. The effect of encouragement and discouragement on performance. *J. Ed. Psychol.*, 1923, 14, 21–26.

Hartmann, G. W. Precision and accuracy. *Arch. Psychol.*, 1928, No. 100, pp. 42.

Hurlock, E. B. An evaluation of certain incentives used in school work. *J. Educ. Psychol.*, 1925, 3, 145–159.

Hurlock, E. B. The use of group rivalry as a school incentive. *J. Abn. & Soc. Psychol.*, 1927, 22, 278–290.

Hurlock, E. B. The value of praise and reproof as incentives. *Arch. Psychol.*, 1924, 11, No. 71, pp. 78.

Jersild, A. T. Mental set and shift. *Arch. Psychol.*, 1927, No. 89, pp. 81.

Kefauver, G. N. The relative influence of fatigue on pupils of different levels of mentality. *J. Educ. Psychol.*, 1928, 19, 25–30.

Kitson, H. D. A study of the output of workers under a particular wage incentive. *Univ. J. Bus.*, 1922, 1, 54–68.

Klineberg, O. An experimental study of speed and other factors in racial differences. *Arch. Psychol.*, 1928, No. 93, pp. 111.

Knight, F. B., and Remmers, H. H. Fluctuation in mental production when motivation is the main variable. *J. Appl. Psychol.*, 1923, 7, 209–223.

Laird, D. A. How the college student responds to different incentives to work. *Ped. Sem.*, 1923, 30, 366–370. Also: Changes due to razzing. *J. Exper. Psychol.*, 1923, 8, 50.

Leiner, M. Experimentelle Untersuchungen der Geistigen Arbeitsleistungen von Schülern höherer Lehraustallten. *Arch. f. d. ges. Psychol.*, 1927, 58, 187–229.

Leuba, C. J. A preliminary experiment to quantify an incentive and its effects. *J. Abn. & Soc. Psychol.*, 1930, 25, 275–288.

Lewin, K., and Hoppe, F. Erfolg und Misserfolg. *Psychol. Forsch.*, 1931, 14, 1–62.

Maller, J. B. An experimental study of certain coöperative tendencies. *Relig. Educ.*, 1928, 23, 361–363.

Mayo, E. B. Reverie and industrial fatigue. *J. Pers. Res.*, 1924, 3, 273–281.

Menias, R. Ueber die beeinflussung der geistigen Arbeit durch gemütliche Vorgänge. *Kraepelin Psychol. Arbeiten*, 1925, 8, 217.

Poppelreuter, W. Analyse der Erziehung zur Exactheitsarbeit nach Experimental-psychologischer methods. *Zsch. f. Angewand. Psychol.*, 1927, 29, 1–40.

Rexroad, C. N. Administering electric shock for inaccuracy in continuous multiple choice reactions. *J. Exper. Psychol.*, 1926, 9, 1–18.

Robinson, E. S., and Bills, A. G. Two factors in the work decrement. *J. Exper. Psychol.*, 1926, 9, 415–444.

Rounds, G. H. Is the latent time of the Achilles tendon reflex a criterion of speed in mental reactions? *Arch. Psychol.*, 1927, 95, p. 91.

Sullivan, E. T. Mood in relation to performance. *Arch. Psychol.*, 1922, No. 53, 71.

Thompson, L. A. Measuring susceptibility to monotony. *Person. J.*, 1929, 8, 172.

Thorndike, E. L. On the relation between speed and accuracy in addition. *J. Educ. Psychol.*, 1914, 5, 537.

Triplett, N. The dynamogenic factors in pace-making and competition. *Amer. J. Psychol.*, 1898, 9, 507–533.

Vaughn, J. Positive vs negative instruction. An experimental study of the effects of various types of instruction on behavior. *Publ. Nat. Bur. Casualty and Surety Underwriters*, 1928, 2.

Vernon, P. E. The psychology of rowing. *Brit. J. Psychol.*, 1928, 18, 317–331.

Whittemore. I. C. The influence of competition on performance; an experimental study. *J. Abn. & Soc. Psychol.*, 1924, 19, 236–253.

Windmöller, O. Die Beziehungen zwischen Arbeitschnelligkeit und Arbeitsgüte. *Psychotechnische Zsch.*, 1930, 5, 1–13.

Wright, W. R. Some effects of incentives on work and fatigue. *Psychol. Rev.*, 1906, 13, 23–34.

Wyatt, S. An experimental study of the psychology of the repetitive process. *Brit. J. Psychol.*, 1927, 3, 192–209.

Part Six—Emotional and Affective Processes

CHAPTER XXVII

THE ORGANIC BASIS OF EMOTION

IN THE old tripartite division of mental activity into cognition, affection, and volition, the position occupied by emotions was between affection and volition. Emotions are certainly not cognitive, as are sensory, perceptual, and reflective processes. And in spite of their dynamogenic character, they are not completely described as tendencies toward action or volitions. Their most distinctive character is their affective quality, so that it is common to classify emotions and affects together. The main differences seem to be (1) that affects are simple and unique, while emotions are complex patterns of sensory, affective, and volitional elements; and (2) that emotions are more intense, widespread processes. They are so important an aspect of motivation that discussions of the topic of motives center largely around the subject of emotion. In accord with tradition, the discussion of emotion and affection will be kept separate.

The experimental work on emotion has centered around certain major problems, such as (a) the nature of the emotional process, to what extent visceral, and glandular, and to what extent cortical; (b) the expression of the emotions; (c) the differentiation of one emotion from another; (d) the experimental testing of the theories of emotion; (e) the biological utility of emotions; (f) their native basis; (g) their conditioning, and (h) the measurement of emotionality.

While considerable work has been done from the introspective angle, the greatest proportion of experiments have been of the objective instrumental type designed to get at measurable physiological changes.

THE PHYSIOLOGY OF EMOTION

The main obstacles in the way of a scientific study of emotion are the unstable character of these states and the difficulty of producing genuine emotions in the laboratory. Hardly less important is the extreme widespreadness and complexity of the whole process. Like affects, and unlike sensory processes, emotions are dissipated by close attention to, or analysis of them. The stimulus very quickly loses its capacity to arouse the process; the reaction is sudden and unpredictable; and the stages follow one another rapidly. Nevertheless, by concentrating upon only one stage or part process and ignoring the rest, it is possible to isolate certain features. The criteria for emotion have never been sharply defined. For example, it is sometimes assumed that an emotion is present when the characteristic somatic changes occur, whether or not the subjective experience can be proved to be present. Thus Sherrington assumed that a dog, in whom visceral innervation had been severed, was having the emotion of rage, because he snarled and showed his teeth on presentation of the appropriate stimulus; and Watson gave the name emotion to those reactions of new-born infants to loud noise, restraint, and tickling. Yet others have objected to evidence for the presence of emotion based solely on observable somatic changes without the subjective pattern. Historically, the visceral changes were noticed first, and were described by Aristotle and others; but in recent times, this viewpoint had been abandoned and was revived by the James-Lange theory.

Rôle of the Visceral Patterns

In order to understand the relation of the viscera to emotion, it is essential to know the way in which the innervation of the viscera is related to the central nervous system. The system which controls the response of smooth muscles and glands is called, as a whole, the autonomic system.

The autonomic nervous system. — This system is composed of efferent nerves whose cell bodies lie in ganglia situated alongside of the spinal column. They receive impulses from

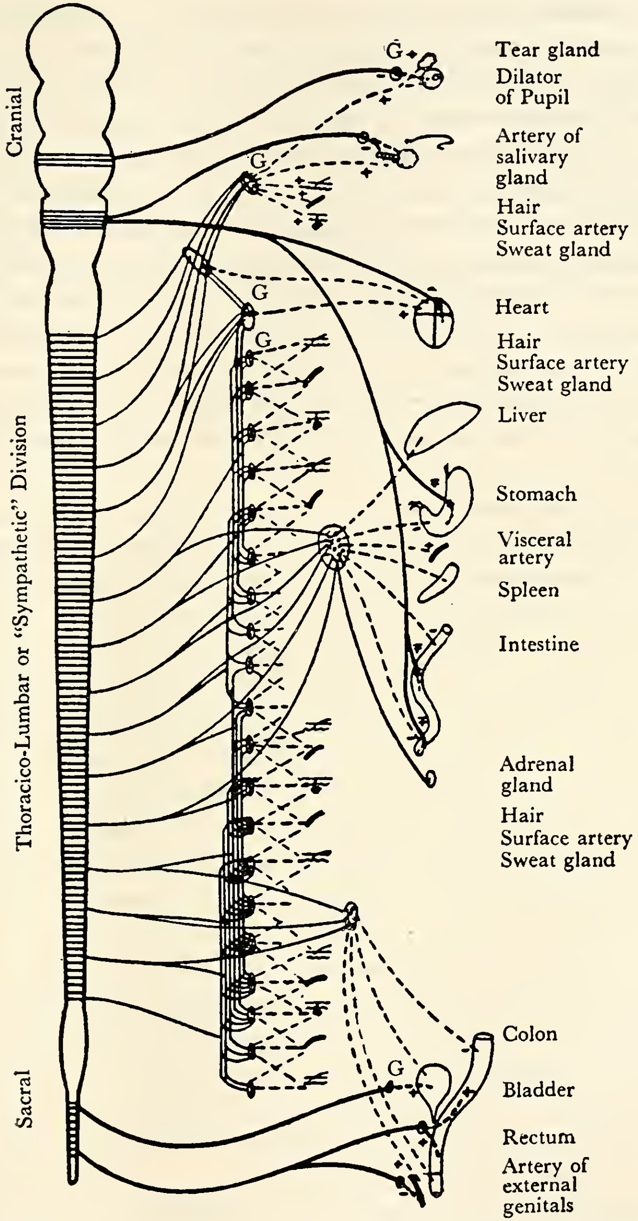


FIG. 110. Diagram of the more important distributors of the autonomic nervous system

The preganglionic fibres are in solid lines, the postganglionic in dash lines. A + mark indicates an augmenting effect on the activity of the organ; a — mark indicates a depressive or inhibitive effect. After Cannon.

nerves whose cell bodies are located in the spinal cord. Therefore they carry efferent impulses from the central nervous system, and differ from the skeletal motor nerves only in that it requires two to reach from the spinal cord to the viscera, via the autonomic ganglia; whereas one skeletal motor nerve is sufficient to connect spinal cord and skeletal muscle. The autonomic nerves connecting the spinal cord with the autonomic ganglia are called the preganglionic nerves; those extending from the ganglia to the visceral effectors are the postganglionic. The afferent nerves returning from the viscera to the central nervous system do not belong to the autonomic system, but like all the other sensory nerves have their cell bodies in the sensory ganglia, and hence belong to the central nervous system.

The preganglionic fibres of the autonomic system emerge from the spinal cord at different levels, which can be grouped into separate systems. One system, called the *cranial,* is composed of fibres from the third, seventh, ninth, and tenth cranial nerves. Another, called the thoraco-lumbar or *sympathetic* system, is composed of fibres from the thoracic and upper lumbar segments of the cord. The third, called the *sacral* division, is composed of fibres from the sacral spinal segments. The cranial and sacral divisions are often grouped together and called the parasympathetic system. Thus we have two major divisions of the autonomic nervous system — the sympathetic and the parasympathetic, which operate more or less in opposition to each other.

The ganglia of the sympathetic system are of two sorts, the lateral ganglia and the collateral ganglia. The former send their fibres out through the spinal nerves to the blood vessels of skin and skeletal muscles, the sweat glands, and the smooth muscles of the hairs. The latter, forming the solar plexus and inferior mesenteric ganglia, send fibres to innervate the abdominal viscera and their blood vessels. It can thus be seen that the fibres of the sympathetic system are widely distributed throughout the body. " They include," says Bard, " vasoconstrictor fibres to the small blood vessels of the abdominal organs, skin, and other parts, accelerator fibres to the heart, secretory fibres to the sweat glands, inhibitory fibres to the smooth muscle of the gastro-intestinal tract, motor fibres to smooth muscles of the hairs, fibres supplying the liver which carry impulses that act to release sugar into the blood, constrictor fibres to the spleen, dilator fibres to the bronchioles, cervical sympathetic fibres to the eyes causing dilatation of the pupils, retraction of the nictating membranes, and projection of the eye forward in the orbit, fibres to the peloric viscera, and finally, secretory fibres to the medullary portion of the adrenal glands." Cannon has emphasized the arrangement of the sympathetic system for diffuse discharge, so that it can act as a whole. When the adrenal medulla is innervated it discharges into the blood stream a chemical agent capable of inducing practically all of the changes which occur when the entire sympathetic is active. The effect of such integrated action of the sympathetic is to mobilize the organism's energy. Blood sugar is increased, digestion delayed, circulation accelerated, respiration facilitated, red corpuscles increased, sweat gland activity increased, and muscular fatigue reduced by action of adrenin. Cannon has therefore called this the emergency function of the sympathetico-adrenal system.

The parasympathetic nerves on the other hand are organized to act independently. Their ganglia lie, not along the spine, but in the organ stimulated, and their postganglionic fibres are very short. The cranial division supplies motor impulses to the ciliary and sphincter muscles of the eye, and secretory and vasodilator impulses to the salivary glands and mucous membranes of the buccal region, and through the vagus it supplies inhibitory fibres to the heart and motor fibres to the gastro-intestinal tract. The sacral division causes contraction of the colon, rectum, and bladder, and vasodilation in the external generative organs. Thus the cranial division contributes to the vegetative and nutritive functions of the body, while the sacral division discharges wastes, under normal conditions of functioning.

We observe, then, that most visceral regions receive innervation from both the sympathetic and parasympathetic systems. These two systems act in opposition. Where one exerts a positive effect, the other exerts a negative. For example, the sympathetic excites the heart, the cranial depresses it; the sympathetic inhibits the gastro-intestinal tract, the parasympathetic sends active motor impulses to it.

Autonomic control of the viscera in emotion. — We are now prepared to consider what happens to the autonomic control of the viscera in emotion. (1) Digestion is promoted by pleasant affective states and emotions, and is inhibited by unpleasant ones. This takes place through a facilitation or depression of the salivary secretion and flow of gastric juice, and the stimulation or inhibition of gastro-intestinal peristalsis. The positive effect is exerted by the cranial autonomic through the vagi, while the negative effect is exerted through the sympathetic. (2) Strong emotions, as anger and fear, arouse the emergency function of the sympathetic-adrenal system. This involves excitation of the adrenin-secreting cells which in turn produce the combined effects which would result from discharge of impulses from the entire sympathetic system. The heart is accelerated, vasoconstriction causes high arterial pressure, the blood sugar content rises, sweat gland activity increases, the pupils are dilated, blood clotting is hastened, muscle fatigue delayed, and respiration facilitated by dilatation of the bronchioles. Some of these effects are produced directly by sympathetic innervation, others indirectly by action of released adrenin. All these effects tend toward preparation of the organism for vigorous action.

Experimental evidence

Most of the experimental evidence for the visceral changes in emotion has been contributed by Cannon, and is reported in his book, "Bodily Changes in Pain, Hunger, Fear, and Rage." But one or two experiments will be described illustrating the study of the main visceral changes.

Gastro-intestinal effects. Pavlov demonstrated for animals, and Cannon for animals and human beings, that both the salivary secretion and the gastric secretion are altered by emotional stimulation of the subject. X-ray examination of the progress of food through the intestinal tract shows that the process is inhibited by unpleasant affective stimuli, or intense stimulation of a pleasant sort, while mild pleasant stimulation promotes the action.

Brunswick studied the tonus of the stomach, duodenum, and rectum under emotional stimulation. Balloons were introduced into the cavities, equipped with tubes leading out to many tambours with recording markers attached so that kymographic curves could be secured of the contractions. The emotional stimuli were pistol shots; plunging the room in darkness; pistol threats; dashing water in the face; odors of decayed flesh, urine, and faeces; rats placed on the subject's face; large snake placed on body; electric shock; subcutaneous injection of adrenin; reading personal letters; and reading exciting passages. In this way the following emotional attitudes were evoked in varying degrees: Fear, startle, surprise, amusement, disgust, shame, relief, tenseness, pleasantness, unpleasantness, wonder, resistance, admiration, envy, and delight. Most of these emotional attitudes were called out only in mild degree. Ten subjects were used. The results cannot be interpreted in terms of particular emotions because of inconsistency, and the tendency toward compensatory emotional reactions; but it is possible to differentiate between the effects of pleasant and unpleasant emotions, in terms of specific changes. The former involve a heightened tonus, the latter a lowered tonus, except disgust which has a specifically tonic effect on the stomach. A technique similar to that of Brunswick was used by Landis in securing gastric and rectal contractions as part of a study of severe emotional disturbance. The stimulus was a severe electric shock applied to the palm of the hand; and the experimental period was preceded by a forty-six hour fast and thirty-six hours of insomnia. Three subjects were used. The immediate result of the stimulation was to initiate gastric contractions in one subject, and to cause a temporary stoppage in another, but it is uncertain whether these contractions were true gastric rhythms or caused by diaphragmatic pressure. Rectal contractions were stopped.

Blood volume changes have been studied with the plethysmograph, in the case of the milder emotional reactions to pleasant and unpleasant stimuli. The early work was done to test the Wundtian theory of feeling. Lehmann was an important contributor of plethysmographic studies. There seems to be evidence pointing to an increase in peripheral volume accompanying pleasant, and a decrease accompanying unpleasant stimuli. But against this, there is contrary evidence. For example, Shepard using a finger and an arm plethysmograph found that the reaction to both pleasant and unpleasant stimuli is almost universally a decrease in volume of the peripheral flow. Contrary to this the volume at the brain was found to increase. This was determined by testing the blood volume through a trepanned area in the skull of an injured subject. Auditory, visual, gustatory, and other stimuli were used of opposite affective values. It is evident that no specificity of blood volume change can be correlated with particular emotional states.

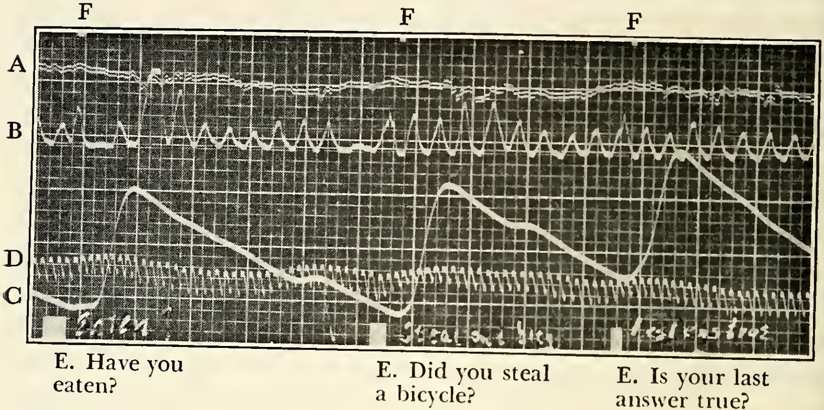


FIG. 111. A photopolygraphic record from a deception test given by Dr. J. A. Larson at the Illinois Institute for Juvenile Research, using the behavior research photopolygraph

White Lines Indicate Seconds.

A. Movement of Left Hand
B. Respiration
C. Galvanic Skin Reflex
D. Blood Pressure from Ankle
E. Signal of Question
F. Signal of Response

Blood pressure. Measurements of blood pressure are obtained by use of the sphygmomanometer, which expresses pressure in terms of millimeters on a mercury scale. The normal systolic pressure is around 120 millimeters, the diastolic in the neighborhood of 90. A method has been devised by Erlanger for obtaining a continuous kymographic record of the rises and falls in pressure, which is a considerable improvement on the clinical sphygmomanometer. In recent years, the blood pressure method of detecting emotions has been widely used in connection with the so-called " lie detection " technique. Marston was the first to use the blood pressure method, and it has been used widely in criminal investigations by Larson and others. Marston concluded that an increase of over ten points in the systolic pressure was indicative of guilt, and claimed a high degree of accuracy in practice. Larson used the Erlanger continuous record, and gave direct questions for stimuli, rather than using a formal list of stimulus words. He found that the particular change in pressure varied with the temperament of the subject. Either a rise or fall might occur, and the particular form of the change was not so important as the time relations to the stimulus. Moreover, the changes differed from either the normal pressure fluctuations or those due to anger, fear, etc. Larson was able to select the guilty subject before confession in about 90% of the cases studied.

Landis in a series of studies was unable to find any constant characteristic of the systolic blood pressure changes accompanying emotional experiences, and in most cases no more variation than was obtained from a series of measurements taken at 15 second intervals while the subject was passively reading. He also used the Erlanger continuous curve technique in the study on severe emotional shock previously described. There was a gradual decrease in the "pulse-pressure," a measure obtained by subtracting the diastolic from the systolic pressure; but there was no characteristic pattern for any particular emotion.

Electrocardiograms. Blatz obtained electrocardiograph records (i.e. photographic records of the deflection of a galvanometer string caused by the electrical phenomena accompanying the beating of the heart) of subjects in whom the emotion of fear was aroused. To produce strong fear, he placed his subjects in a chair which could be made to fall backward sharply when released. He observed the following changes: (a) an immediate initial acceleration followed by a decided retardation, then a less marked but more prolonged acceleration phase, and a subsequent gradual retardation,

(b) an initial increase in force of heart beat persisting for six minutes and (c) a marked irregularity of the cardiac rhythm. These effects appeared in all subjects.

Blood chemistry. There is some evidence of an increased alkalinity of blood and saliva in emotional states and in prolonged nervous conditions, in excess of the normal. There is also an increase in blood sugar as Cannon has discovered. The urine shows glycosuria. In psychopathic subjects there is some evidence that depressed or stuporous stages are characterized by glycemia whereas the euphoric stages show hypoglycemia.

Breathing. One of the most constant accompaniments of emotional excitement is a change in rate and depth of respiration. Most physiological studies of emotion have included pneumographic records. For example, Blatz, in the aforementioned study, used an electrical pneumograph which showed the beginning of inspiration and expiration but not the amplitude. He observed (a) an immediately retarded rate in 9 out of 11 records, (b) an increase in the respiratory index, and (c) an exaggeration of the inspiratory phase at the instant of falling. Skaggs found that the period immediately following an electric shock was characterized by a large increase in amplitude of both thoracic and abdominal curves.

The inspiration-expiration ratio has been found to have some significance in detecting the emotion accompanying deception. Burtt reported, in 1921, a study on the respiratory ratio in truth and falsehood. The method had been used extensively by Benussi, and he had claimed highly consistent results by comparing the ratio before and after telling a falsehood. The ratio before lying was less than that afterward. With truth-telling it was the reverse. Burtt tested this hypothesis with two different types of stimulus material. The first type consisted of cards containing letters and numbers arranged in geometrical shapes which were presented visually to the subject. He was later questioned about them and was told to lie about some and tell the truth about others. The second type consisted of short accounts of crimes which the subject was supposed to have committed which he must either lie or tell the truth about. The results for one series are as follows: The average difference between the expiration-inspiration ratio before and after truth-telling was .04 while that for lying was —.05, a significant difference; but, contrary to the claims of Benussi, large exceptions occurred.

Metabolism. In general, there is an increase in the metabolic rate accompanying emotional stimuli or the expectation of such stimuli. Totten (1925) performed a series of tests of metabolic rate with induced emotional states. In seven of these tests there was no change in the rate of oxygen consumption; while in six the oxygen consumption increased following the stimulation, in amounts ranging from 4.9 to 25 per cent. Totten introduced controls to determine whether the change was caused by increased action of the respiratory muscles, or increased tension of the limbs, with negative results. She concluded that the effect was probably due to the dilatation of the bronchi caused by the action of the autonomic, in emotional states. Landis, in a previously described experiment on the effects of severe electric shock on subjects who had gone without food and sleep for a couple of days beforehand, studied the metabolic rate regularly for several days before. Three subjects showed increases in rate of from 16 to 48 per cent as a result of anticipating the shock. But within eight minutes after the occurrence of the shock, it had returned to normal.

Action of Endocrines in Emotion

Among the glands which probably function importantly in emotion are the adrenals, the thyroid, the pituitary, and the gonads. Cannon's work has demonstrated the function of adrenalin in delaying fatigue in skeletal muscle, in relaxing certain smooth muscle tissue, in affecting the sympathetic system in such a way as to alter blood supply, and in changing the blood pressure through its action on arterial and heart muscle; he has also demonstrated the action of adrenalin on the pancreas in releasing glycogen, and in hastening the clotting of blood; breathing is also affected through relaxation of the bronchioles. Beyond this little is known. But from the behavior of clinical cases in hyper- and hypo-thyroidism, it appears that thyroxin acts to influence the characteristic moods of emotions, and to lower the threshold of excitability. Regarding pituitrin nothing is known except that the gland is enlarged by continuous emotional excitement. The gonads, of course, function specifically in the emotion accompanying sex behavior.

The Central Mechanisms Involved in Emotion

It has been pointed out that the autonomic nervous system is innervated through the spinal nerves. Hence the source of the visceral changes is impulses from the central nervous system. We must ultimately look there for the initiation of the pattern of changes. Conceivably, the seat of emotions could be in the spinal cord, or the midbrain and thalamus, or the cerebrum. But as a result of three main lines of evidence, it is possible to locate the seat of emotional organization in the hypothalamus with some assurance. These lines of evidence are, (a) extirpation of portions of animal nervous systems; (b) effects of anaesthesias on humans, and (c) clinical evidence from lesions in human nervous systems.

Results of extirpation experiments. Cannon and others have shown that decorticated dogs and cats display "sham rage." He also has evidence of functioning of the sympathetic system as an emergency mechanism.

Secondly, Sherrington demonstrated that animals whose brain stem has been truncated in the region of the midbrain never show emotion — such as the sham rage, though they do show a very slight tendency toward mild affective behavior. Yet the central source of direct control of sympathetic activity is in the medulla, which is responsible for release of adrenin, and cardiac acceleration and vasoconstriction. But these centres do not actually operate without stimulation from regions higher up.

Finally, Bard experimented with the ablation of various amounts of the brain stem and found that he could remove the hemispheres, the corpora striata, and the cranial half of the diencephalon and thalamus, without destroying emotional behavior. Also parts of emotional patterns could be elicited in spinal animals, but no coördinated emotion ever occurred. But when the hypothalamus was removed, the coördinated emotions failed to occur. Therefore Bard concluded that the seat of coördination or integration of the emotional pattern is located at the base of the diencephalon, in the region of the hypothalamus.

Anaesthetics which are cortical depressants, like Nitrous Oxide, cause an intermediate stage of behavior before deep anaesthesia is reached, in which emotional behavior — laughter and crying — is released. This is probably due to the release of subcortical levels from cortical inhibition.

Brain lesions bring out certain effects. Wilson has shown that lesions which interfere with voluntary control of the muscles involved in the expression of emotions do not interfere with emotional expression but enhance it. Uncontrollable laughing and crying are released by such lesions in corticothalamic fibres. And conversely Bailey gives clinical evidence for emotional paralysis with retention of normal voluntary control in patients who have tumors in the region of the thalamus.

The conclusion to be drawn is apparently that the cortex exerts an inhibitive effect upon the emotional display, while the actual pattern of discharge is subcortically organized. However, the acquisition of new emotional attitudes, i.e. the process by which conditioned emotional responses are acquired, is no doubt a function of cortical integration. It is probably *native* emotional patterns which are thalamically organized. Another point to bear in mind is that the original stimulus to emotional discharge is a function of the perception of exciting external situations. Hence most initiation of emotional expression originates in the cortical response to external stimuli.

THE PROBLEM OF DIFFERENTIATING THE EMOTIONS

There are two closely related experimental problems with reference to the expression of emotion, through overt and implicit channels. One problem is the factual one of just how emotion in general is expressed; how wide-spread is the skeletal muscle and smooth muscle involvement. And of course this question has important bearing on the theory as to how emotion acquires its peculiar subjective quality as a unique affective experience. The other problem is this: How do we differentiate between different emotions? Is this differentiation based on some clearly discernible difference in the objective pattern of expression of the different emotions, whereby we can tell them apart, a difference which is reflected in consciousness as a peculiar qualitative pattern for each different emotion? Or is there a more or less common group of bodily changes in all emotion, so that we must speak of the expression of emotion in general rather than of this or that particular emotion — anger, fear, sorrow, joy, etc.? And in the latter case how are we able to tell what emotion we ourselves are having?

Expression of Emotion. On the overt side, the problem becomes one of determining what skeletal muscles of face and limbs and trunk are involved. Is there a characteristic reaction of these muscles which can be used as a criterion of the presence of emotional upset? Darwin was one of the first to be interested in a systematic analysis of the overt expressions of emotions. His work led him to a formulation of certain explanatory theories. One of these assumes that the forms of expression are survivals of biologically useful acts; such as the baring of the canine tooth in the angry sneer as a preparation for effective biting. Another assumes that an excess of neural energy is released, and that it tends to discharge over innate pathways. A third hypothesis is that of the antithetical nature of emotional expressions in antithetical emotional attitudes, as the lowering of the brows in scowling and the raising of the brows in the opposite mood, causing the smile. Other authors, as James, have advanced similar principles. Duchenne experimented with facial expressions by systematically stimulating separate facial muscles with an electric current and photographing the expression which resulted. It was found that many of the typical expressions of emotion could be simulated by the contraction of isolated muscles. Another theory held that there are only three fundamental forms of expression: joy, grief, and surprise, involving three kinds of neural action: heightened tension, lowered facial tension, and inhibition, from reciprocal innervation of antagonists.

Differentiating Emotions. In 1914 Feleky reported an experiment in the judgment of emotions from photographs of the face. She had pictures taken of herself in which she tried to express all the various forms of emotion, by her facial expression. Eighty-six such photographs were presented to one hundred judges, who decided what emotions were indicated. The results show considerable confusion, though some emotions seem easier to identify than others. Langfeld repeated this experiment with sketches of emotions made by artists from poses. His results show that, as with Feleky, the scorn-contempt group of emotions give the highest consistency of judgment. Laughter was seldom mistaken for other emotions. But fear and anger were confused, as were also surprise and suspicion. Langfeld's pictures were taken from Rudolph's " Der Ausdruck des Menschen," which are sketches from photographs of an actor who posed for the different emotional expressions. They are therefore somewhat exaggerated. Introspections of the subjects point to the use of kinaesthetic imagery and the recall of actual emotional situations as an aid in the interpretation of the pictures. That is, the person judging tended to think himself into the emotional situation or to remember the face of familiar persons in typical emotional situations.

Recently Boring and Titchener brought out a demonstration model consisting of parts of faces which can be put together to depict the expression of the various emotions. The effects are obtained by interchanging a set of mouths, eyes, brows, and noses. The resulting faces are known as the Piderit faces. Buzby selected six of these, anger, dismay, horror, disdain, disgust, and bewilderment and had 716 students judge which of a list of eighteen possible emotions was expressed. He found that the total facial expressions for horror, disdain, disgust and bewilderment gave the highest percentage of correct judgments, while anger and dismay gave the least. The upper part of the face proved more important than the mouth in making judgments. Women's judgments proved somewhat more accurate than men's.

Landis, in a series of studies, made still photographic records and moving picture records of subjects at the instant they were being subjected to a variety of emotional stimuli. The stimuli consisted of classical and jazz music, paintings of nudes and sex-exciting pictures, paintings of the crucifixion, pictures of diseases, a bucket of frogs into which the subject's hand was thrust, and electric shock. A preliminary test showed not only a great deal of individual variability in facial expression, but wide differences between the expressions of real emotion and the stereotyped expressions which the subjects gave when they were told to simulate the same emotion. In a further study, he subjected twenty-four subjects, 12 men and 12 women, to much more intense emotional stimuli. A list of 1200 photographs was obtained, and the accompanying emotions experienced by the subjects were recorded. These photographs were analyzed to determine the muscle groups involved in the facial expression, and the extent of movement involved. Landis found no particular pattern of muscle contractions which consistently accompanied each emotion. There were large individual variations, and each individual tended to have a characteristic pattern for the expression of emotion, but not for the differential expression of different emotions. Each subject had only two or three such characteristic patterns of expression. Pain, surprise, and anger gave the greatest amount of movement, while disgust and sex were least marked. It is interesting that men showed more facial reactions than women.

The difficulty in judging, even from moving pictures, what emotion the subject is showing has been brought out clearly in an experiment of Sherman on the emotional reactions of infants. He used four different situations — pain, restraint of limbs, dropping the child in mid-air, and hunger. He required a group of obstetrical nurses and medical students to judge from moving pictures what emotions the child was displaying. In one condition they were allowed to see the stimulus situation causing the emotional behavior while in the other condition they had to judge entirely from the bodily expression. Sherman found that without the aid of the knowledge of the stimulus, judges were hardly more accurate in their diagnoses than chance would dictate.

Other features of overt emotional expression are laughter and crying, vocal utterance, and patterns of the large skeletal musculature and body as a whole. Considerable speculation has occurred regarding all these forms, but little experimental evidence exists. The whole question is complicated by the fact that most overt expression is sooner or later used for communication of meaning, as a sort of language, through which individuals convey their moods to others. On this account the overt expression is sure to become conventionalized and exaggerated in conformance to certain social concepts. Certainly the emotional pantomime of cinema actors cannot be taken as representative of the overt forms of spontaneous expression of emotion. This pantomime is a conventionalized language.

In the field of musical expression, Seashore and his coworkers, Metfessel and others, have made careful studies of the methods by which emotion is conveyed through the voice, and through other instruments, by means of the vibrato, etc.

The implicit expression of emotion through visceral patterns has already been described. It will be recalled that, while emotion in general is characterized by definite alterations in the visceral patterns, yet there were no characteristic changes which were exclusively attached to any one emotion. Mobilization of the blood supply, increased breathing, abeyance of digestion, etc. are present in all violent emotional states.

Two problems regarding the differentiation of emotions present themselves. One is the question how other persons judge what particular emotion a given person is having. The other is the problem of how the individual himself differentiates his own emotional state. There is a common conviction that we have a unique experience for each emotion — anger, rage, joy, etc. Does this uniqueness of experience, provided it exists, arise from a uniqueness of the visceral or skeletal pattern?

Experimental evidence has given a tentative answer to both these questions. There is not enough specificity in the natural overt expressions of the various emotions, facial, vocal, and bodily, to enable judges to determine with any high degree of correctness, what particular emotion is taking place.

It is only through a knowledge of the particular stimulus which has called out the response that such a judgment can be accurately given. If the subject has received a severe electric shock, we can judge that the emotion he is suffering is not joy. When Sherman's judges knew that the infant subject had been pricked by a pin, they did not interpret its behavior wrongly. It is not the overt response alone, but the meaningful relation between the stimulus and the response that forms the basis for correct judgment.

Similarly, there is little evidence that the internal visceral pattern is specific enough so that the specificity of the subject's experienced emotion could be derived from it. Experiments in which subjects have been given doses of adrenalin which have produced the visceral changes of violent emotion, the rapid heart, the sweating, etc. have left them subjectively cold emotionally. There must be added, to the vague generalized visceral background of sensory content, the perception of a definite emotional stimulus or exciting external situation. What more must be present we are not prepared to say. But at least there must be present a stimulating situation which is perceived by the subject to be meaningfully related to the visceral and skeletal disturbance which he experiences.

REFERENCES

Bailey, P., and Fulton, J. F. Tumors in the region of the third ventricle. *Jour. Nerv. and Mental Diseases,* 1929, 69, 158.

Bard, P. A diencephalic mechanism for the expression of rage with special reference to the sympathetic nervous system. *Amer. J. Physiol.,* 1928, 84, 490–515.

Bard, P. Emotion: 1. Neuro-humoral basis of emotional reactions. *Foundations of Experimental Psychology.* Worcester, Mass., Clark Univ. Press, 1929, pp. 449–487. See p. 453.

Benussi, V. Die Atmungsymptome der Lüge. *Arch. f. d. ges. Psychol.,* 1914, 31, 244–273.

Blatz, W. E. The cardiac, respiratory, and electrical phenomena involved in the emotion of fear. *J. Exper. Psychol.,* 1925, 8, 109–132.

Boring, E. G., and Titchener, E. B. A model for the demonstration of facial expression. *Amer. J. Psychol.,* 1923, 34, 471–486.

Brunswick, D. The effects of emotional stimuli on the gastrointestinal tone. *J. Comp. Psychol.,* 1924, 4, 19–79; 225–287.

Burtt, H. E. The inspiration-expiration ratio during truth and falsehood. *J. Exper. Psychol.,* 1921, 4, 1–23.

Buzby, D. E. The interpretation of facial expression. *Amer. J. Psychol.,* 1924, 35, 602–604.

Cannon, W. B. Bodily changes in pain, hunger, fear and rage. N. Y.: D. Appleton, 1915.

Darwin, C. R. The expression of the emotions in man and animals. N. Y.: D. Appleton, 1913.

Erlanger, J., and Festerling, E. G. Respiratory waves of blood pressure, with an investigation of a method for making continuous blood pressure records in man. *J. Exper. Med.*, 1912, 15, 370.

Feleky, A. M. The expression of emotions. *Psychol. Rev.*, 1914, 21, 33–41.

Landis, C. Studies of emotional reactions. I. A preliminary study of facial expression. *J. Exper. Psychol.*, 1924, 7, 325–341. II. General behavior and facial expression. *J. Comp. Psychol.*, 1924, 4, 447–509.

Landis, C. Studies of emotional reactions. IV. Metabolic rate. *Amer. J. Physiol.*, 1925, 74, 188–203.

Landis, C. Studies of emotional reactions. V. Severe emotional upset. *J. Comp. Psychol.*, 1926, 6, 221–242.

Lange, C. G., and James W. The emotions. *Psychology classics.* Vol. I. Williams and Wilkins, Balt., 1922.

Langfeld, H. S. The judgement of emotions from facial expressions. *J. Abn. & Soc. Psychol.*, 1918, 13, 172–184.

Larson, J. A. The cardio-pneumo-psychogram in deception. *J. Exper. Psychol.*, 1923, 6, 420–454.

Lehmann, A. Die Hauptgesetze des Menschlichen Gefuhlsleben. Leipzig. 1892.

Marston, W. M. Systolic blood pressure symptoms of deception. *J. Exper. Psychol.*, 1917, 2, 117–163.

Metfessel, M. F. Technique for objective studies of the vocal art. *Psychol. Monog.*, 1926, 36, No. 1, 1–40.

Pavlov, I. P. The work of the digestive glands. (2nd ed.) London: Griffin, 1910, pp. 266.

Seashore, C. E. Phonophotography as a new approach to the psychology of emotion. Feelings and Emotions. The Wittenburg Symposium, Worcester, Mass.: Clark Univ. Press, 1928, pp. 206–211.

Shepard, J. F. Organic changes and feeling. *Amer. J. Psychol.*, 1906, 17, 522–584.

Sherman, M. The differentiation of emotional responses in infants. I and II. *J. Comp. Psychol.*, 1928, 7, 265–284; 335–351.

Sherrington, C. S. Experiments on the value of vascular and visceral factors for the genesis of emotion. *Proc. Roy. Soc.*, 1900, 66, 397.

Skaggs, E. B. Changes in pulse, breathing, and steadiness under conditions of startledness and excited expectancy. *J. Comp. Psychol.*, 1926, 6, 303–315.

Totten, E. Oxygen consumption during emotional stimulation. *Comp. Psychol. Monog.*, 1925, 3, No. 13, pp. 79.

Watson, J. B. Psychology from the standpoint of a behaviorist. Phila.: J. B. Lippincott, 1929, pp. 229.

Wilson, S. A. K. Pathological laughing and crying. *J. Neur. and Psychopathol.*, 1924, 4, 299–333.

CHAPTER XXVIII

THE NATURE AND MEASUREMENT OF EMOTIONS

THEORIES OF EMOTION EXPERIMENTALLY TESTED

THE TWO outstanding theories of emotion, from the point of view of the attention devoted to them, are (1) the James-Lange theory, and (2) Cannon's Thalamic Theory. Other theories can be looked upon as modifications or variations of these. Previous to the development of the James-Lange theory, emotion was considered to consist in a unique and unanalyzable experience, which was thought to be the direct and immediate consequent of the act of perception of the emotional stimulus. The organic and bodily disturbances were known and recognized, but were assumed to be concomitants or expressions of the mental state rather than in any sense determinants of it. And the overt behavior patterns such as running, or crying, were assumed to be *results* of the emotion. James, therefore, was a decided innovator, when he advanced his theory that there was no such unique experience, independent of the bodily changes, and insisted that the subjective emotion consisted in the complex of sensations resulting from the bodily changes. The bodily changes must therefore have occurred before the conscious emotion could occur, hence the conscious emotion could not be the *cause* of the bodily events, but these must have been caused directly by the perceived stimulus. The conscious emotion, then, is a result of the bodily changes. James therefore advanced his famous paradox that "We feel sorry because we cry, angry because we strike, afraid because we tremble." Both Lange and James assumed that the different particular emotions were differentiated by the specificity of the bodily changes in each case. The main difference was that Lange stressed almost exclusively the circulatory changes, whereas James included all the visceral processes and in addition the gross skeletal patterns including the overt acts, the consummatory behavior. Modified statements of the theory have since been given by Dunlap, Carr and others which differ from the position of James in the following respects:

Whereas James insisted upon identifying the emotion with the *conscious experience* of the bodily changes as introspectively discovered, behavioristic psychologists identify the emotion with the bodily changes themselves, and ignore the conscious experiences. Carr takes a modified position, intermediate between these extremes. The emotion is a psychophysiological process. It is neither exclusively the subjective experience of the bodily changes, nor exclusively the bodily changes. Both aspects are parts of the totality which is the emotion.

Whereas James included the overt behavior of running, in fear, striking, in anger, etc., in the bodily changes which are experienced as the emotion, Carr excludes these. The emotion does not wait upon the consummatory act, but helps to determine, to reinforce the act.

Finally, whereas James assumed that the bodily patterns are highly specific, giving rise to distinctly characteristic experiences for each different shade of emotion, Carr argues that the specificity is not so much a function of the bodily changes, which are vague and general, as of the perceptual situation which was the stimulus to the emotion.

These varying points of view can be expressed by the following schematic picture, which indicates the temporal order of events; and the phase which constitutes the actual emotion according to each theory is given in italics:

ORDER OF EVENTS IN EMOTION

		I	II	III	IV	V
I.	Traditional Theory	Emotional Stimulus	Perception of it	*Unique conscious experience*	Bodily changes	Overt behavior
II.	James-Lange Theory	Emotional Stimulus	Perception of it	Bodily changes	Overt behavior	*Conscious experience of III and IV*
III.	Behavioristic Interpretation	Emotional Stimulus		*Bodily changes and overt behavior*		
IV.	Carr's Interpretation	Emotional Stimulus	Perception of it	*Bodily changes and the conscious experience accompanying them*		Overt behavior

Experimental Evidence for and against the James-Lange Theory

The evidence which James quotes in defense of his theory is chiefly anecdotal in type. The following main lines of evidence are given:

Introspective evidence that if one imagines a strong emotion, and then abstracts from the experience all feelings of bodily symptoms, nothing is left over. Since introspectors fail to agree on this point, the evidence is inconclusive.

Clinical cases of subjects who are absolutely anaesthetic inside and out, but not paralytic, so that emotional situations can arouse the bodily changes, yet who report no subjective experience of emotion. The evidence from such cases is contradictory. James quotes a case reported by Strumpell in which complete anaesthesia existed except for one eye and one ear. This subject showed the outward expression of shame and grief on occasions, as well as surprise, fear, and anger, but he may not have felt these emotions subjectively.

Pathological cases in which an emotion is felt as though no adequate cause is present except a disorder of the visceral patterns. Morbid fear is possibly caused by the increased beating of heart and other visceral changes which are set off by other than emotional stimuli; and some subjects report alleviation of the morbid fear by voluntary control of the disturbed viscera.

When emotional expressions are voluntarily induced in a cold-blooded way, as by actors in playing emotional rôles on the stage, the subjective emotional experience is often induced and the actor really lives the emotion. But James found that the evidence here is contradictory. Some actors declare that they remain subjectively cold.

The experimental evidence collected by critics of the James-Lange theory is more concrete and systematic. The two chief critics have been Sherrington and Cannon.

Sherrington centers his objection in the fact that when the visceral changes are prevented from occurring, nevertheless the emotional behavior is not altered. He sectioned the cervical spinal cord and vagus nerves in dogs, so that connection was destroyed between the abdominal viscera and brain, and the vasomotor nerves were separated from the vasomotor center. Breathing and innervation of head organs was left intact. Such dogs snarled and showed all the emotional behavior of anger to the appropriate stimuli. But Sherrington's case is weak in that he has failed to demonstrate the absence of a *subjective* emotion; and in that the overt behavior is, according to James, not a result, but a cause of the emotion. It is not caused by but accompanies the visceral disturbance, according to James, and hence could easily occur without it.

Cannon and others removed the sympathetic division of the autonomic system in cats, thus destroying the sensations from the viscera, yet such cats hissed, snarled, showed the teeth, and showed all signs of rage except erecting the hairs, when a barking dog was presented as a stimulus. The same objections apply here as to Sherrington's dogs.

More direct evidence is given by Dana of a human subject in whom the entire sympathetic system and the entire somatic system below the neck were eliminated, yet the subjective emotional experiences of the patient were unchanged. The woman suffered a fracture of the neck which also caused complete paralysis of the skeletal muscles. Yet she reported feeling affection, grief, joy, and anger.

Cannon quotes evidence from cases in whom the visceral patterns of emotion have been artificially produced by injection of adrenin into normal persons without causing them to experience any emotion. One wonders whether the subjects were sufficiently expert in diagnosing their subjective feelings to give a reliable report on this point. Quite recently Landis and Hunt experimented with intramuscular injections of 0.5, 1.0, and 1.5 cc of 1–1000 solution of adrenalin chloride in 27 psychopathic subjects. A control dose of salt solution was alternately given. The results show no effect from the control dose, and a few cases of genuine "emotion-objective" from the adrenalin, thereby corroborating the previous work of Cantril and Hunt on normals. The force of Cannon's criticism is certainly shaken by these results.

One of Cannon's chief criticisms is that the visceral patterns could not possibly furnish the differentia for all the varied emotional states because the same visceral changes occur in unlike emotions. He argues on experimental evidence that fear and anger both involve arousal of the entire sympathetic system. Besides, many non-emotional bodily states, as those caused by cold and by violent exercise, as running, involve similar visceral patterns to fear and rage, yet are not accompanied by the emotional experience.

Neither can the skeletal pattern of changes accompanying emotions contribute to the specificity of the subjective emotional experience, for two reasons:

1. Wilson gives clinical evidence that in cases of pathological laughing and crying, the subject may subjectively be experiencing the opposite emotion to the one expressed. Hence, his subjective state is not dictated by his skeletal pattern.

2. Paralysis of the skeletal musculature may occur, such that scarcely any overt skeletal contractions occur, as in advanced paralysis agitans, tabes, arthritis, etc. — without destroying the capacity for experiencing emotions. Dana's woman patient already referred to is a case in point.

While none of the evidence is completely conclusive, the cumulative effect weighs heavily against the James-Lange theory. However, whether emotional experiences in the absence of any visceral or skeletal sensory component are identical with emotions experienced under normal conditions is very doubtful. The truth of James's assertion, that, after all, visceral sensory experiences *are present* during emotion, must still be admitted. And such experiences must contribute something to the total experience. The theory requires the assumption that thalamic processes may be a source of affective experiences, so that the same sorts of sensory experiences which seem to be of bodily origin can be assumed to be of thalamic origin. Otherwise when the innervation from the body is cut off, there could be no emotional consciousness.

The experimental evidence for the cortico-thalamic theory is largely from clinical cases in which the connections between cortex and thalamus have been disturbed.

When cortical control is removed from the thalamus by lesions of the connecting fibres, uncontrolled emotional display has been observed to result.

When the afferent connections from thalamus to cortex are destroyed, subjective emotional states are interfered with.

Experimental Evidence for the Thalamic Theory

Cannon has proposed, in opposition to the James-Lange theory, a theory to the effect that normal emotion results from the interaction between cortical and thalamic patterns. This removes the essential locus of the emotions from the viscera and soma and places it in the brain. It assumes, first, that the actual neural mechanisms, whose patterned discharge sets off the sympathetic system and gives rise to the bodily changes, are located at the base of the thalamus. For this there is experimental evidence, as we have already seen. Next, it assumes that this same thalamic region also sends afferent impulses to the cortex which gives us the characteristic subjective sensory pattern of emotion. He therefore explains the subjective pattern on the basis of thalamic afferent impulses instead of afferent impulses from the viscera. Finally, the theory assumes that the thalamic patterns are constantly modified by efferent impulses from the cortex. Under ordinary conditions the cortex exerts an inhibitory action on the thalamic mechanisms, so that emotional patterns are not constantly being released. But, given the perception of an exciting stimulus, the cortex releases the thalamic mechanisms. Even then, however, the cortex directs and controls these thalamic mechanisms, so that their discharge is modified and directed in terms of the total situation as cortically perceived. Also, since the thalamic patterns are innately determined, the basis for acquired or conditioned forms of emotional display must be cortically determined. The expression, however, is always via the thalamus.

When the thalamus is intact, even though afferent visceral impulses are cut off, the characteristic subjective affective pattern remains.

But when the diencephalon is so widely affected by a diseased condition that both afferent and efferent connections are destroyed, neither the bodily expression of emotion nor the subjective experience occur.

THE NATIVE BASIS OF EMOTIONS

Most theories of emotion attempt to give some explanation of their origin. In the case of the violent emotional responses like extreme fear, the behavior is so lacking in adaptiveness, at least to civilized life, that it is inconceivable that the pattern should have been ontogenetically acquired. Such patterns seem impossible of explanation except as evolutionary survivals of a more primitive life. But if they are to be considered as hereditary heirlooms, it should be possible to show that at some time they had biological utility or survival value. So the problem of the native basis of emotions raises several questions. (1) Are emotions inherited? (2) What is their biological utility? (3) To what extent can they be modified by training? The experimental evidence on the first two questions follows. The third question will be treated under the topic of conditioning and reconditioning of emotions.

Are Emotions Inherited? Among the various tests or criteria suggested for demonstrating the instinctive basis of a response, such as universality, resistance to modification, biological utility, appearance at birth or soon after, etc., the last criterion is probably the best. If it can be demonstrated that the response in question is present soon after birth, in anything like a complete pattern, it is evidence of congenital and probably hereditary origin. The converse is not necessarily true, since the appearance of the instinctive response might wait for maturation of essential structures.

Experimental Evidence for Presence of Emotions at Birth. There are at least three aspects of an emotion that might be native. That is, the specificity of the emotional pattern might take three different forms. First, the stimulus might be specific. That is, there might be a certain limited number of native stimuli capable of eliciting emotion. Second, the specificity might be in the subjective feeling or experience. Unfortunately this cannot be experimentally tested because infants cannot report on their feelings. Third, the specificity might be in the bodily response pattern — the somatic and visceral changes. Or all three of these might be specific. A distinction should be made here between specificity of emotion in general as distinguished from other sorts of response, and specificity of particular emotions, as distinguished from one another.

Watson performed the pioneer experiments on emotions of infants. Using, as subjects, infants during the first weeks of life, he tested them with a variety of stimuli. With some of the stimuli positive results were secured, with others, negative results. But Watson was able to identify only three emotional patterns in the infant responses. These he called fear, rage, and love (or sex), and he concludes that these are the only emotional reactions belonging to the "original and fundamental nature of man." Fear was called out by two specific stimuli; the sudden removal of support as in dropping, and loud sounds. The pattern of the response he also considers specific — a catching of the breath, random clutching, closing eyes and crying. Other stimuli, supposed to natively elicit fear, such as darkness, proved ineffective.

Rage was called out by hampering of the infant's movements. The response pattern consists in stiffening of the body, screaming, holding of breath, and slashing movements of the arms.

Love was elicited by stimulating the erogenous zones, by stroking, tickling, patting, rocking, etc. The response consists in smiling, cessation of crying, cooing, and extension of arms.

Watson hazards the assumption that with excessively strong or long continued stimulation, the reaction of the infant would be similar to that of animals, i.e., the complete paralysis, or " death faint." This is speculative, however, for there is no direct experimental evidence to verify it.

All other stimuli tried gave mostly negative results. Three infants, 165, 125, and 124 days old were submitted to the following stimuli: (a) Animals were presented, a black cat, a pigeon, a rabbit, and a white rat. Only reaching movements occurred. (b) The baby was placed in the dark, and a waste paper basket was set on fire. Again no fear reaction occurred. The experiments were also tried with the child left apparently alone. The results were still negative. Other experimenters have tried as stimuli, snakes, other animals, and grotesque false faces, with negative results.

The conclusion from Watson's experiment is that both the stimuli and the responses are natively specific.

On the other hand, Sherman's experiment, previously mentioned, throws doubt upon the specificity of the response pattern. Sherman subjected infants under eight days of age to the following emotional stimuli — hunger, dropping suddenly, restraint of head and face, and sticking with a needle. Four types of judges were used — graduate students in psychology, third year medical students, obstetrical nurses, and normal school students. They were asked to judge what emotion the infants were displaying, (a) Where they were shown moving pictures of the behavior of the infants, but were not allowed to see the stimulus; (b) When allowed to see the stimulus; (c) When they actually saw the live infants in the nursery but did not know the stimulus; and (d) With knowledge of stimulus. Sherman found that the degree of psychological and medical knowledge did not materially increase the accuracy of the judgments which were extremely variable. But with knowledge of the stimulus given, the judgments were much more accurate. The conclusion is that the pattern of response is not so specific as Watson supposed, but that judgments are made on the basis of specificity of the stimulus. Sherman's later study on the cries of infants showed no greater specificity.

THE BIOLOGICAL UTILITY OF EMOTIONS

The evidence for the biological utility of emotional reactions is of two sorts: (a) The careful study of skeletal patterns by Darwin and others on humans and animals, and the speculations based thereon as to their evolutionary development; (b) The study of the internal visceral and glandular reactions by Cannon and others and the deductions therefrom concerning the emergency function of the sympathetico-adrenal system.

Darwin propounded the principle of serviceable associated habits, which assumes that any act performed in response to a biological need tends to form a habit which will later be called out by similar situations whether it happens to be serviceable at the time or not. He assumes that such habits may be phylogenetically as well as ontogenetically acquired. As he states the theory it assumes the inheritance of acquired characters, but it can be equally well stated in terms of natural selection so as to avoid this implication. Thus the canine teeth are bared in rage because this was at some time serviceable in preparation for more effective biting, etc. If we take this point of view we must consider many forms of emotional expression survivals of acts which were serviceable at an earlier period in our evolutionary development. Darwin does not insist that all aspects of emotional behavior can be explained in this manner. He employs two other explanatory principles, that of antithetical movements and that of mechanical nervous discharge. But it is in this principle of survival of serviceable habits that the factor of biological utility is invoked.

Cannon's assumption of biological utility is nonspecific. As we have indicated, he denies any specific patterns in response to specific emotional situations. He merely assumes a generalized pattern of visceral changes for all emotion. But this generalized pattern is assumed to have survival value. It prepares the organism for strenuous action in an emergency. The more rapid clotting of blood, the increased blood flow, the inhibition of purely vegetative functions, all have a survival value in situations demanding strenuous action.

Now, since emotions often occur in situations in which strenuous action is not called for, Cannon must make the further assumption that the emotional pattern is an evolutionary relic, which continues to persist long after the situations demanding it have ceased to occur.

THE MEASUREMENT OF EMOTIONS

A DISTINCT experimental problem is raised by the practical requirement of a good technique for testing emotions. Several situations arise, such as (a) the study of individual differences in emotionality, (b) the degree of emotional response to different situations, (c) the detection of the presence of implicit emotional response when no overt expression occurs, and (d) the study of abnormal forms of emotion in psychopathic subjects.

The chief methods are:

1. Electrical methods; the psychogalvanic reflex.
2. Blood changes; the plethysmograph and sphygmomanometer.
3. Verbal methods; the free association method, and the emotionality questionnaires.

The more elaborate physiological devices used in studying visceral processes are inapplicable as practical tests because of their elaborateness.

Electrical Methods. The Psychogalvanic Reflex. Since the first discovery of the electrical phenomenon of the body, called by Veraguth " the psychogalvanic reflex," it has been thought to have a definite relation to emotional states. There appear to be two different forms of the electrical phenomenon, obtained in two different ways. One is the change in resistance of the body to a weak electric current passed through it and in circuit with a Wheatstone bridge. This is called the phenomenon of Feré because he first used the technique. It requires an exosomatic current. This is the most commonly used technique. The other is the variations in the electromotive force of the body, which can be measured with a galvanometer, and is known as Tarchanoff's phenomenon, because he originated the method. No external current is used.

Most any form of galvanometer may be used in obtaining the psychogalvanic reflex. A convenient model for practical purposes, because portable and compact, and equipped with continuous photographic recording device, is a model designed by Wechsler. Recently, Darrow has developed a type of resistance box, known as the "Behavior Research Resistance Box," which eliminates many sources of error and gives a continuous quantitative record of both resistance level and resistance changes in the subject. A diagram is shown in Figure 112. The important point is that the resistance in three arms of the Wheatstone bridge is kept constant; the only changes that occur are in the subject's arm of the bridge. Different effects have been claimed to result from the use of different types of electrodes, especially from dry or wet electrodes, the latter being less subject to mechanical effects of poor contact. But the essential features consist of placing the body in circuit with an extremely weak direct electric current which is relayed through a galvanometer.

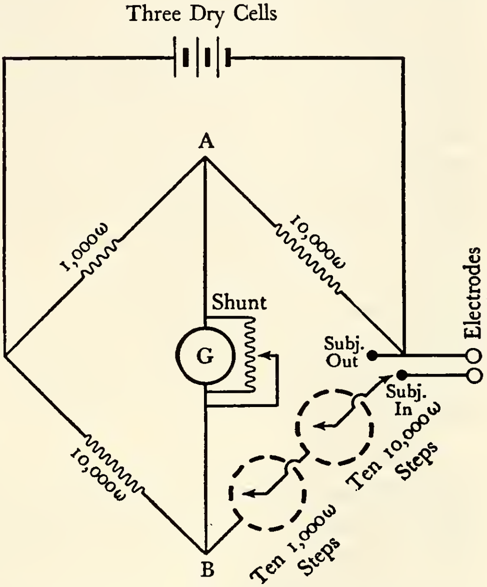


FIG. 112. A simplified diagram of the behavior research resistance box

Courtesy of Dr. C. W. Darrow

There is considerable disagreement among students of the psychogalvanic reflex as to just what it is physically, physiologically, and psychologically. The physical basis seems to have been settled by experiments of Gildemeister which show the apparent change in body resistance to be due to changes in amount and rate of polarization. As to the physiological basis, three main hypotheses have been offered; that it results from action of the sweat glands in the skin; that it is caused by the electrical effects accompanying muscular contractions. Due to the careful investigations of Darrow and others, the sweat gland hypothesis has been pretty well established, but this does not mean that muscular contractions do not influence the phenomenon.

With regard to the psychological basis of the phenomenon, there is great disagreement. It has always been thought to be related to emotional and affective reactions. But it has proved extremely disappointing as a measure of emotional involvement. Two recent psychologists who have defended the theory that only emotionally toned stimuli elicit the phenomenon are Pieron and Wechsler. Others have attributed it either to sensation, as did Sidis, or attention, or conation, as Aveling has argued. A considerable number have found that mental work causes the psychogalvanic reflex especially when it requires effort.

Experimental evidence.—A few experiments illustrative of the application of the technique to studies of emotion are the following:

Washburn and others tested individual differences in emotionality as correlated with the psychogalvanic reflex. They found that (1) the galvanic deflections are larger in the case of a cheerful than in that of a depressed group of subjects; (2) subjects judged to be emotional, when asked to recall emotional situations, have larger galvanic deflections than subjects judged to be unemotional; (3) there is a correlation between the size of the deflections and the degree of emotionality of the subject, and between size of deflections and the introspectively reported intensity of the recalled emotion. Washburn concludes that it is possible to distinguish an emotional from a calm group on the basis of the psychogalvanic.

Wechsler studied the question of a general emotionality. He presented his subjects with a large variety of different affective stimuli. He did not find any subject who reacted emotionally to all stimuli, but found that individuals tend to react emotionally toward certain particular stimuli.

Whately Smith found that the affective value of various word stimuli could be determined more reliably by the galvanometric method than by an association test. He recommends the method for detecting unconscious complexes. Prince and Peterson found it possible to detect the presence of an aroused emotional complex of which the subject was totally unaware. Using a subject with multiple personality, in the hypnotic trance, they obtained galvanic deflections for stimulus words whose meaning was unknown to the personality dominant at the time.

Against this positive evidence, W. S. Brown found no relation between the psychogalvanic reflex and emotional tendencies in subjects as judged by teachers, although the reliability of the judgments is questioned by the author. And Aveling found both that affectively toned experiences often give no deflections, but that when deflections do occur the subject seldom reports the presence of affective experience. In a recent evaluation of the technique Landis concludes that the reflex can be elicited by so wide a number of different physiological and psychological factors that it cannot be in any sense a reliable indicator or measure of emotion.

However, he points out that two anatomists, Schilf and Schuberth, demonstrated in 1922 that the electrical response occurred only when the autonomic nervous connections between effector and receptor were intact, and concluded that the reflex is specifically controlled by the autonomic nervous system. Therefore, to the extent that the reflex gives evidence of autonomic disturbance, and to the extent that autonomic disturbance is a characteristic of emotion, we may say that the reflex is correlated with emotional states.

Where the psychogalvanic reflex has actually been used to test the emotionality of individuals, it has been found impracticable. For example, Woodrow tested young children in a nursery school daily over a period of time. Not only was there no correlation between their attendant's judgments of their emotionality and their deflection scores, but the variations of one child's scores from day to day were as large as the differences between children. A test whose reliability is so low cannot have much validity.

Blood and Respiration Changes. The two best physiological indices of the presence of emotion are the blood pressur and the inspiration-expiration ratio. The work of Marston Larson, Burtt, and others who used these techniques in detecting deception has been described. The systolic pressur changes seem to be most diagnostic; though Landis found th "pulse-pressure," i.e., the ratio between the systolic and diastolic, best. It is necessary to use a continuous curve of th pressure changes graphically recorded, because it is the temporal relation of the change to the time of giving the stimulu that is most diagnostic rather than the direction or amoun of the change. Hence a technique of the Erlanger type i best. The results are of qualitative rather than quantitativ significance. Moreover a combination of the blood pressur and inspiration-expiration ratio scores has been found superior to either alone.

Verbal Methods. The verbal response methods will always be more widely used than the preceding techniques, because of their greater simplicity. In fact they are limited only by the capacity of the subject to make verbal responses and follow directions. They have been used on insane as well as sane. The results with insane are less valuable because of the difficulty in getting rapport. Young children and a-ments could not be tested in this way either.

The two chief methods are (a) the free association technique, and (b) the emotional questionnaires.

Free Association. — It is unnecessary to describe the free association test again. This has been done in Chapter XVII. When it is used to detect emotions or test emotionality, the list of stimulus words is chosen in such a way that a few critical words are scattered amongst a number of indifferent words. The responses of the subject to the critical words are studied carefully, and his behavior is observed. Unusually long or variable reaction times, or failure to hear the stimulus, or overt signs of conflict, are considered diagnostic signs of emotion. The responses themselves are considered diagnostic if they are unnatural or farfetched, or if there is a forced avoidance of relevant associations, or avoidance of repetition of previous responses to critical words on a retest. Often the free association test is used not to detect the presence of particular emotional complexes with reference to particular subjects, but to determine the general emotionality of the subject. In the latter case it is the *total number* of emotionally toned stimuli to which the subject gives diagnostic responses that is used as an index of his emotionality.

Usually the free association technique is used in conjunction with the blood pressure, breathing, and psychogalvanic records.

Questionnaires. — One of the first emotionality questionnaires was the Woodworth Personal Data sheet, a psychoneurotic inventory. It consisted of a series of direct questions like the following:

"Do you often have pains in any part of the body?"

"Does it make you uneasy to have to cross a wide street or open square?"

"Did you ever have a strong desire to commit suicide?"

The total number of such questions which a subject responds to positively gives a rough index of his degree of emotionality. The chief defect of the test is that a reasonably alert subject could easily answer in such a way as to either minimize or exaggerate his emotionality score. Several modifications and expansions of this type of test have been devised recently, among which are the Thurstone Personality Schedule and the Bernreuter Inventory.

A somewhat different type is the Pressy Cross Out Test. This consists of four parts. In the first part several short lists of words are given such as "naked, snicker, wonder, spit, fight," and the subject is told to cross out every word he dislikes and to draw a circle around the one that is most unpleasant to him. In the second he is to cross out those which are related in his mind to a key word, as "SLEEP: grade, ache, fright, tongue, worry." In the third group he is to cross out the morally wrong words; and in the last, the words which describe things he has worried about. Obviously the test is a combination of the free association and questionnaire techniques. The advantage is claimed for it that it is not as easy for an intelligent subject to "fake" it as in the case of the questionnaire.

The chief need at present is more adequate criteria in the form of accurate independent judgments of emotionality of subjects against which all these tests can be thoroughly tested for their validity.

THE ACQUIRED BASIS OF EMOTIONS

Thus far we have made no distinction between the native element in emotions and the acquired basis. It is evident that, in their native form, the patterns and the stimuli which call them out are quite limited. But in adults the number of emotional situations is almost unlimited. And the pattern of expression is considerably modified. Often a visceral upheaval is concealed behind an external calm, as in the case of the "poker face." This inhibition of overt expression is an acquired condition. To what extent does the internal or visceral pattern get inhibited or modified by learning? And what are the effects of inhibiting or modifying the subjective phase of the emotion? Is this phase subject to control through learning? There are two related problems. One is the factual problem of what modifications actually do occur in the overt and internal patterns of emotion, and in the number and variety of stimuli capable of eliciting them. The other is the practical problem of how to experimentally control and change undesirable forms of emotion and produce desirable emotional patterns.

The first problem was attacked by Watson, in his studies of conditioning of emotions in infants. He first demonstrated that infants react emotionally to a very limited number of native stimuli. Therefore it must be assumed that they acquire the tendency to react emotionally to all other stimuli as a result of experience. Watson adopted the concept of the "conditioned reflex," formulated first by the physiologist Pavlov, to account for the process by which new stimuli are made to elicit responses which were originally elicited only by natively adequate stimuli. This concept, as applied to conditioned emotional stimuli, would mean, then, that whereas fear is natively elicited only by loud noises and dropping, it may come to be elicited by any other stimulus, if this stimulus is frequently presented simultaneously with the native stimulus. Watson performed the following type of experiment to test this hypothesis:

An eleven-months-old infant was first subjected to a series of stimuli and it was found that he showed the fear reaction only to loud noises. The loud noise, in this case the striking of a steel bar behind the child's head, was therefore the native unconditioned stimulus. A white rat was used as the conditioned stimulus. A preliminary test showed no fear reaction to the rat. But after eight simultaneous presentations of rat and loud noise together, the infant showed the fear reaction to the rat also, crying and trying to escape.

In order to determine whether the fear reaction had transferred to other similar objects, the infant was again tested five days later. He still showed the fear response to the rat, and also to a hairy dog, and a fur coat, and slightly to cotton wool. But all other objects which were in the room when the conditioning took place failed to elicit the emotion. The emotional response had therefore been conditioned to the white rat, and transferred from this to all furry objects.

Against the exclusive emphasis upon the environmental factors in widening the emotional life, Gesell has pointed out the importance of the concept of maturation, or internal growth. He objects to discussing the primary emotions as though they were elementary stable phenomena subject only to the changes of social conditioning. He describes the reactions of children at various age levels to such a stimulus as confinement in a small enclosed space. At ten weeks it elicits no disquietude; at 20 weeks, mild apprehension; and, at 30 weeks, crying and fright. It is suggested that such a pattern is as much the product of organic growth as the development of prehension. However the difficulties of separating maturation from experience are tremendous.

Other experimental evidence with regard to the acquisition of emotional patterns is largely of the clinical sort. A study of abnormal fear, rage, love, sorrow, and joy reactions points to the conclusion that any one of the native emotional attitudes can become attached to any sort of stimulus as a result of particular vivid experiences. The conditioning of fear to unusual situations and stimuli gives rise to the long list of special phobias; acrophobia, fear of elevation; claustrophobia, fear of inclosed places; anthropophobia, fear of men, etc. In many cases direct questioning of such clinical cases discloses the origin of the phobia in some early life experience in which the conditioned stimulus was very frequently or vividly presented in conjunction with some unconditioned stimulus. In other cases a patient's use of the free association technique in either the discreet or continuous form will uncover the same facts. Occasionally hypnosis proves effective in assisting the dissociated memory of the experience under which the emotional attitude was acquired.

Conditioned love reactions appear in the clinic in the form of the various perversions, and sex fetishes. Individuals are reported who are emotionally excited only by a shoe or a garment, rather than by the normal heterosexual love object. An acquired basis for these abnormal emotional reactions can usually be traced.

Experimental Control of Emotions

The practical problem, to what extent undesirable emotional patterns can be removed and replaced by desirable ones, has also been left largely to the clinical field of psychiatry. But the techniques used by psychiatrists and particularly by psychoanalysts are too loose and lacking in objectivity and rigid control to enable one to test them experimentally. The most carefully controlled studies have thus far been made on children.

M. C. Jones experimented with the eradication of undesirable emotional reactions in children. The subjects were selected from 70 children from three months to seven years of age, of normal intelligence and social status, in an institution for temporary care. They were chosen on the basis of showing marked fear reactions to stimuli which do not normally elicit fear, such as being left alone, being presented with false faces, or with animals like rabbits, frogs, etc. Seven methods of treatment were tried, which were called, respectively, (1) elimination through disuse, (2) verbal appeal, (3) negative adaptation, (4) repression, (5) distraction, (6) direct conditioning, and (7) social imitation. The first method proved ineffective after a two months' trial. The second method, in which daily conversations about the stimulus object connecting it with pleasant associations were tried, proved ineffective after two weeks. The third method consisted in familiarizing the child with the presence of the object. It was sometimes effective, but sometimes produced a summation effect. Repression was exerted by use of ridicule, social teasing, and scolding, but failed to remove the fear reaction. Distraction was exerted by directing the child's attention positively toward some interesting activity while the fear object was present. It temporarily diverted, but did not permanently remove the fear response. The last two methods, conditioning and social imitation, proved the most effective. The former consisted in attempting to associate with the fear object a definite stimulus capable of arousing a positive pleasurable reaction in the child. For example, in one case, a positive stimulus (candy and food) was introduced simultaneously with the fear object (rabbit), with the result that the fear reaction disappeared after a few trials. The social imitation method consists of letting the child who shows fear toward a given object (rabbit) see other children play with the rabbit and pet it. This method may involve conditioning also, with social participation as the pleasurable stimulus.

In adults, motivation and stimulus situations are so much more complicated that these simple procedures are inapplicable. Emotional reëducation has been attempted, however, by Franz and others with some success. This field is one of the most vital and yet least explored parts of psychology.

REFERENCES

Aveling, F. The conative indications of the psycho-galvanic phenomenon. *Proc. Eighth Internat. Cong. of Psychol.*, 1926, 8, 227–234.

Brown, W. S. A note on the psychogalvanic reflex, considered in conjunction with estimates of character qualities. *Brit. J. Psychol.* (Gen. Sec.), 1925, 16, 130–135.

Cannon, W. B. Bodily changes in pain, hunger. fear and rage. N. Y.: D. Appleton, 1915.

Dana, C. L. The anatomic seat of the emotions. A discussion of the James-Lange theory. *Arch. Neur. and Psychiat.*, 1921, 6, 1–8.

Darrow, C. W. Sensory, secretory, and electrical changes in the skin, following bodily excitation. *J. Exper. Psychol.*, 1927, 10, 197–226.

Darwin, C. Expressions of emotion in man and animals. N. Y.: D. Appleton, 1873.

Dunlap, K. Emotion as dynamic background. Feelings and emotions; The

Wittenberg Symposium. Worcester, Mass., Clark Univ. Press, 1928, pp. 150–160.

Feré, C. Note sur les modifications de la résistance électrique sous l'influence des excitations sensorielles et des émotions. *C. R. de la Soc. de Biologie,* 1888, 40, p. 217.

Franz, S. I. Nervous and mental re-education. N. Y.: Macmillan, 1924, pp. 225.

Gesell, A. Maturation and infant behavior pattern. *Psychol. Rev.,* 1929, 36, 307.

Gildemeister, M. Zur Theorie der Sekundär-elektromotorischen Eigenschaften der menschlichen Haut. *Pflüger's Archiv. f. d. ges Physiol.,* 1922, 195, 112–122.

Jones, M. C. The elimination of children's fears. *J. Exper. Psychol.,* 1924, 7, 382–390.

Landis, C. Psychology and the psychogalvanic reflex. *Psychol. Rev.,* 1930, 37, 381–398.

Landis, C., and Hunt, W. A. Adrenalin and emotion. *Psychol. Rev.,* 1932, 39, 467–486.

Marston, W. M. Systolic blood pressure symptoms of deception. *J. Exper. Psychol.,* 1917, 2, 117–163.

Pieron, H. Les variations physiogalvaniques comme phénomène d'expression des émotions. *Rev. de Psychiatrie,* 1910, pp. 486–506.

Prince, M., and Peterson, F. Experiments in psycho-galvanic reactions from co-conscious (subconscious) ideas in a case of multiple personality. *J. Abn. Psychol.,* 1908, 3, 114–131.

Schilf and Schuberth. *Pflüger's Archiv. f. d. ges. Physiol.,* 1922, 78.

Sherman, M. The differentiation of emotional responses in infants. I and II. *J. Comp. Psychol.,* 1928, 7, 265–284; 335–351.

Sherrington, C. S. Experiments on the value of vascular and visceral factors for the genesis of emotions. *Proc. Roy. Soc.,* 1900, 66, 397.

Sidis, B. The nature and cause of the galvanic phenomenon. *J. Abn. & Soc. Psychol.,* 1910, 5, 69–74.

Smith, W. W. A note on the use of the psychogalvanic reflex. *Brit. J. Psychol.,* 1921, 12, 282–288.

Strumpell, A. *Ziemssen's Deutsches Archiv. für Klinische Medecin,* XXII, 321. Referred to James' Principles of Psychology, Vol. II, p. 455.

Tarchanoff, J. Ueber die galvanischen Erscheinungen in der Haut des menschen bei Reizungen der Sinnesorgane und bei verscheidenen Formen der psychischen Tatigkeit. *Pflüger's Archiv. f. d. ges. Physiol.,* 1890, 46, 46–55.

Veraguth, O., and Brunschweiler. Recherches sur le phénomène psychogalvanique dans quelques cas de troubles sensitifs par blessures cerebrales de guerre. *Rev. Neurol.,* 1918, 34, 151.

Washburn, M. F., Harding, L., Simons, H., and Tomlinson, D. Further experiments on directed recall as a test of cheerful and depressed temperaments. *Amer. J. Psychol.,* 1925, 36, 454–456.

Washburn, M. F., and Pisek, F. Galvanometer experiments with revived emotions as a test of emotional and phlegmatic temperaments. *Amer. J. Psychol.,* 1925, 36, 459–460.

Watson, J. B., and Raynor, R. Conditioned emotional reactions. *J. Exper. Psychol.,* 1920, 3, 1–14.

Wechsler, D. Sur la technique du reflexe psychogalvanique. *J. de Psychol.,* 1922, 19, 172–177.

Wechsler, D. On the specificity of emotional reactions. *Amer. J. Psychol.,* 1925, 36, 424–426.

Wechsler, D. The measurement of emotional reactions; researches on the psychogalvanic reflex. *Arch. Psychol.,* 1925, 12, 1–181.

Wilson, S. A. K. Pathological laughing and crying. *J. Neur. and Psychopathology,* 1924, 4, 299–333.

CHAPTER XXIX

AFFECTION

WE SHALL consider the term affection, or feeling, to refer to that dimension of experience whose extremes are known as pleasantness and unpleasantness. In general, it is distinguished from sensation in being a subjective or personal attitude aroused by, rather than knowledge about, the stimulus; and from emotion in being much more mild and less dynamic. In theory it has been identified with practically every other mental state as well as being considered absolutely unique. To understand the significance of the experimental work on affection it is necessary to be acquainted with the major theories.

THEORIES OF AFFECTION

To begin with, the fact that feeling always occurs as an accompaniment of sensation, and the fact of the close relation between the sensation of pain and the feeling of unpleasantness, have led many to consider affection either a particular kind of sensation coördinate with other sense modalities, or else an attribute of sensation, just as duration is an attribute. But no unique sense organs for affection have been located, and unlike all other attributes, pleasantness and unpleasantness are by no means inseparable aspects of all sensations. Moreover, pain and unpleasantness are not identical because pain is sometimes pleasant, and, unlike pain, unpleasantness may accompany any sort of sense stimulation. Hence the majority of psychologists, particularly structuralists, have considered affection a unique kind of experience — an elemental process — having two qualities, pleasantness and unpleasantness. In defense of this there is the introspective fact that, whereas sensations increase in clearness when attended to, pleasantness and unpleasantness fade out.

Some psychologists who have considered affection an elementary process have held that it involved more than two kinds of experience. Wundt recognized, in addition to pleasantness and unpleasantness, tension and relaxation, and excitement and calm. Relaxation is opposed to tension, and excitement to calm, just as pleasantness is opposed to unpleasantness. This is known as the Tridimensional Theory of Feeling. Royce recognized only two different independent dimensions, pleasantness-unpleasantness and restlessness-quiescence. Wundt's tridimensional theory has stimulated the greatest amount of experimentation.

In addition to the foregoing theories, two recent ones have been advanced which approach the problem differently. One, attributed to Dunlap, assumes that feelings are organic sentienda; that is, they are the complex sensory experiences which come from the body as a result of the internal reaction to the affective stimulus. They might be spoken of as experienced organic reverberations. In this respect Dunlap's theory of feeling is an extension of the James-Lange theory of emotion.

The other theory, that of Carr, called the judgmental theory, assumes that pleasantness and unpleasantness are cognitive judgments about stimuli, based on our past reactions toward them. Thus when I call castor oil unpleasant, that is a cognitive reaction to it, based on my knowledge of my early past reactions to castor oil. To say that I dislike castor oil is to say that I recognize it as an object toward which I have previously reacted, negatively. The explanation of my previous reactions is to be found in the general conditions under which the stimuli were originally presented. A stimulus which does not of its own nature call forth an avoiding reaction, might do so under the proper accompanying conditions. The theory offers an explanation of the fact that most affective reactions are acquired. This theory places affection in the field of perceptual or meaningful processes rather than on a level with elementary processes like sensation.

Experiments in Affection. — A number of experiments have been performed to test the element theory and especially Wundt's tridimensional element theory. Incidentally they throw light on all the theories. These experiments were either introspective, in which subjects were presented with various stimuli to which they were asked to make judgments of pleasant or unpleasant, etc., or they were of the objective type, testing some physiological change concomitant with the affective stimulation or some form of motor expression, such as could be registered by means of an instrument like the automatograph. The introspective approach is known as the Method of Impression, while the opposite approach is designated the Method of Expression. The method of impression has been used in experimentation on Aesthetics. A description of the method follows:

I. *Method of Impression*

Experimental Aesthetics.—Any group of sensory stimuli, as a set of spectral colors, or a series of tones of different pitch, or a collection of different odors, are presented to the subject. The presentation may be made in several different ways, of which the following are illustrative:

Classification. If merely a judgment of pleasant-unpleasant is desired, the subject is presented with each stimulus singly and merely classifies it as pleasant or unpleasant. Or he may assign to it some absolute degree of pleasantness or unpleasantness, as "very pleasant," "mildly pleasant," etc. Or he may be asked to give the stimulus an absolute position on a linear scale ranging from most disagreeable to most agreeable. Usually, however, in addition, an estimate is desired of the relative pleasantness of the various stimuli in the group with relation to each other.

Order of Merit. For this purpose, the simplest way is to have the subject arrange the stimuli in a series in order of relative preference from most pleasant to least pleasant. A more careful procedure is the following:

Paired Comparison. Every stimulus in the set (e.g., colors) is presented with every other color as a pair, and the subject is asked to judge which of the pair is more pleasant. If the group contained 10 colors, then there would be $\frac{10 \cdot 9}{2}$ or

45 paired comparisons to judge. Since, in judgments of this sort, the spatial position of the two compared objects affects the judgment, it is necessary to vary the position of the two stimuli, placing one of them first to the right and then to the left of the other. Whenever two colors are judged equal, and no preference is shown, then each of the pair is accorded a half preference. In this way, the colors can finally be arranged in a unidimensional series from the most pleasant to the least pleasant, in terms of the number of times each was preferred. But a brief consideration will show that this method fails to decide how far apart each of the stimuli is on the scale. Some adjacent stimuli would actually be farther apart in pleasantness than others. Hence a graduated scale must be constructed.

The Graduated Scale. In affective judgments there is no objective scale against which the judgments as to the distance of the stimuli from one another can be checked. Hence it is necessary to obtain some reliable estimate of these relative distances. The subject could probably himself make rough differentiations but they would lack quantitative validity. But if several judgments have been made with regard to each pair of items, then it will be found that certain stimuli are judged more pleasant than certain others one hundred per cent of the time, while others are only judged more pleasant seventy-five per cent of the time. If we make the assumption that equally perceptible differences (i.e., equally often judged differences) are subjectively equal, then we can construct a scale in which each step constitutes a difference which is equally often perceived and is therefore perceptibly equal to every other step on the scale. This method was used by Fechner in arriving at his J.N.D. units in psychophysics. Where the J.N.D.'s have measurable physical dimensions which can be compared with them, a psychophysical equation such as Fechner's can be determined, i.e., $s = K \log R$ where the sensation varies as the logarithm of the stimulus times a constant increment. But in affective reactions there is no objective physical standard to which the subjective steps can be compared.

Just as in the establishment of differential sensory thresholds, the method of adjustment of the stimulus by the subject is often used in aesthetic judgments. For example, the question may be that of deciding the most pleasing point at which to bisect a vertical line. The subject is then allowed to move the bisecting pointer back and forth along the vertical line until he is satisfied. The same procedure may be used in determining the most pleasing interval between two tones. But here one of the tones is held constant and the other is systematically varied by the adjustment which the subject makes. A series of such reactions gives a more reliable estimate than any single reaction, and the stability or reality of the aesthetic attitude can be estimated by the standard deviation of the separate reactions from their average.

Results of Experimental Aesthetics.—Fechner initiated the systematic experiments in this field. The main branches which have been developed are those of (a) form, the aesthetics of lines, areas, etc.; (b) colors, in simple and combined forms; and (c) tones, the aesthetics of tonal combinations. The results of studies in consonance, harmony, and musicality, and the theories which have been offered in explanation of them, have been discussed in the chapter on audition.

Introspective Evidence and Theories of Affection.—In addition to asking the subject to judge whether the stimulus is pleasant or unpleasant, he may be asked to analyze the experience further to determine whether it is distinguishable from the sensory elements involved, whether it is complex or simple, etc. Certain facts have been established in this way.

First, it has been found that pleasantness and unpleasantness disappear when closely attended to. Hence introspective analysis is rendered difficult. And evidence is given favoring the uniqueness of the affective process.

Second, it is usually found that pleasantness and unpleasantness do not occur simultaneously, that they are mutually exclusive.

Third, not all stimuli can be reacted to as distinctly pleasant or unpleasant. There is a state of indifference which is without positive affective tone. This is probably not a third kind of affect, but the absence of affect.

While the foregoing evidence may be said to favor an elemental theory of feeling, there is other recent evidence supporting the notion that feeling is a particular kind of sensory experience which accompanies or is aroused by all sense stimulations which have affective value. Nafe reports introspective evidence that pleasantness is an experience of "bright-pressure," while unpleasantness is an experience of "dull-pressure." While this distinction could hardly account for all the various sorts of feeling which can be distinguished in human experience, nevertheless it might well be the factor which contributes the affective "tone" to the feeling, and which therefore makes it possible to classify every feeling reaction as primarily pleasant or unpleasant.

II. *Method of Expression*

Physiological Evidence. Bain suggested that "states of pleasure are connected with an increase, and states of pain with an abatement of some or all of the vital functions." This distinction might equally well apply to emotions. To what extent can we say that an appreciable change in the vital functions accompanies pleasantness and unpleasantness? The principal tests have been of breathing rate and depth, pulse, and blood volume; the latter has been studied with finger and arm plethysmographs, and, in the Shepard experiment, described earlier, was applied directly to the brain through a trepanned skull.

Wundt gives the following summary of his experimental results:

FEELING	PULSE		BREATHING	
	STRENGTH	SPEED	STRENGTH	SPEED
Tension	—	—	—	—
Calm	—	same	—	—
Unpleasantness	—	+	+	—
Pleasantness	+	—	—	+
Excitation	+	same	+	+
Relief	+	+	+	+

Tension and relief are states produced by requiring the subject to perform some mental operation. Tension accompanies the presentation and relief comes with the successful completion of the task. Tension is accompanied by a slowed breathng and pulse, while relief gives the opposite. But this only holds true for short work periods, and is probably an artifact — i.e., the necessity of holding the breath — rather than being related to any particular feeling tone. Shepard, Stevens, and recently Skaggs all find a large variability in the direction of blood volume change in attention. There is more agreement as to excitement and calm. Excitement always causes an increase and calm a decrease in breathing. With regard to Wundt's results in the case of pleasantness and unpleasantness, there is no agreement. Since there is always a sensory stimulus attended to, when reactions of pleasantness or unpleasantness occur, the physiological effects may come from the attention, rather than from the affect. And frequently pleasantness and unpleasantness are no more than cognitive judgments passed on the stimuli, as Carr suggests, devoid of any marked "feeling tone." Shepard compared the circulatory changes in brain and arm, and found that all agreeable or disagreeable stimuli alike caused a decrease in the volume of blood in the hand and an increase in the brain blood volume. But since all moderate nervous activity produces the same results, the fact has no specific meaning.

Studies of the psychogalvanic reflex in affective reactions are contradictory. Whately Smith used the method in detecting the feeling-tone of word stimuli, and on this basis studied the relation of affective tone to recall. Washburn obtained galvanic deflections from subjects recalling affective and emotional memories, with positive results. But it has been pointed out that the galvanic reaction is elicited by such a variety of stimulating conditions that its specificity for pleasantness and unpleasantness is very slight.

Neurological Evidence. Among theories which attribute affective states to brain conditions, that of Lehmann is an example. He considers pleasantness an index of proper balance between the supply and expenditure of energy by the brain cells, while unpleasantness shows an excess of expenditure, thus accounting for the unpleasantness of all intense or excessive sensory stimulations. Certainly there is no separate group of afferent nerves from the sense organs accounting for affective experiences. Clinical cases of nerve lesions seem to show a capacity to experience pleasant and unpleasant tone in the absence of afferent sensory stimulations and vice versa.

Bodily Movement.— One of the favorite ways of investigating feeling by the method of expression is to record slight muscular contractions. For this purpose the *automatograph* was devised. This instrument is designed to measure both the involuntary tremors of the arm at rest, and the slight movements which are initiated by the presentation of affectively toned stimuli to the subject. The apparatus consists of a flat board suspended by cords from above so as to hang at such a height that it will form a convenient horizontal rest for the forearm of a subject seated beside a table with his arm extending over the table. At one end of the board, beneath the hand, a stylus extends downward so as to just touch a sheet of smoked paper placed on the table directly below. Thus any slight movement of the arm and hand causes the stylus to record a mark on the smoked paper. The subject is now blindfolded and presented with stimuli, usually olfactory. If the stimulus is pleasant, it has been found that the arm tends to make forward excursions, while if it is unpleasant, backward excursions result.

Another test is the following: A preliminary record is obtained of the subject's muscular strength on a finger dynamometer. The normal curve is obtained by exerting a continuous pull at maximal strength for a given time. This is compared with the curve obtained when the subject is presented with pleasant or with unpleasant stimuli — gustatory or olfactory. Feré found that affective stimuli tend to increase the strength of the dynamometer pull and to retard fatigue. But since there is a certain amount of excitement caused by presentation of the stimulus, the findings are highly questionable unless a neutral control stimulus is presented in obtaining the normal curve. Very strong stimuli are necessary to elicit the effect.

RELATION OF AFFECTION TO OTHER PROCESSES

Much of the experimental work on feeling has been carried out in connection with the study of other mental processes. For example, the effect of pleasant and unpleasant material on learning and recall; the influence of affective attitudes on efficiency in mental work; hedonism as a principle of selection in behavior, etc. The experiments have been described under the appropriate topics.

Complex Processes. Motivation

There are two main directions in which emotions enter into complex behavior. On the one hand, they become elaborated through conditioning to form the permanent affective aspects of personality, such as mood and temperament and the systems of sentiments, emotive attitudes and beliefs with which everyone is equipped. Some experimentation is beginning in this direction but the results are chiefly interesting from the point of view of individual differences. Tests have been devised to determine general emotionality, such as the Pressy X-O tests, and particular attitudes of introversion or of ascendency, as the Bernreuter Personality Inventory or the Allport A–S Reaction Test. The extremes of emotional trait are measured by tests of the type of the Woodworth or the Thurstone Psychoneurotic Inventories. Scales have been devised to measure affective attitudes, as Thurstone's Attitude Scales for determining attitudes toward war, toward races, etc., which make possible the accurate allocation of the subject's attitude on an absolute scale of positive-negative attitude. Character traits, as emotional attitudes of a moral significance, like honesty, have been studied notably by Hartshorne and May, to determine their stability and uniformity of operation.

On the other hand, emotions form the core of the complex problem of motivation. The problem of measurement of the strength of various drives has been discussed in connection with the topic of incentives and motives in the chapters on Learning and Work and Fatigue. A method for the determination of the comparative strength of drives has originated in animal psychology, and offers possibilities for use in human psychology. In the form used by Moss, known as the obstruction method, the animal is compelled to cross an electrically charged grill to reach the incentive. The strength of the incentive can be measured by the strength of the shock which the animal will endure to reach that particular incentive. Warden used a similar technique. In the form used by Simmons, the rats were required to learn a maze to secure the incentive and the relative strengths of the incentives were judged in terms of a comparison of the records for speed of learning under the different conditions.

At one time, considerable interest centered in the problem of volition or conation with particular reference to the act of decision or choice preceding overt behavior. Introspective studies of Ach and Wundt, and more recently of Wheeler, have sought an answer to the problem of decision and choice, with the discovery that it is a complex experience involving several stages and not characterized by any one unitary process. Conation has been studied similarly by Aveling, who has identified the psychogalvanic reflex with the conative act, and argues that conation is present as an element in all responses in which the psychogalvanic reflex has appeared. Until a more substantial body of evidence is available, it is impossible to decide whether there really is a unique process of conation or volition, or whether, as the vast majority of psychologists hold, it is merely a name for a logical aspect of the complex process of sensory-motor adjustment.

REFERENCES

Ach, N. Ueber den Willensakt und des Temperament. Leipzig, 1910.

Aveling, F. The psychology of conation and volition. *Brit. J. Psychol.*, 1925, 16, 339–353.

Bain, A. The senses and the intellect. London: Longmans, Green, 1868, pp. 1–714; ref. cited, p. 283.

Carr, H. A. Psychology, N. Y.: Longmans, Green, 1925, pp. 290.

Dunlap, K. The elements of scientific psychology. St. Louis: C. V. Mosby, 1922, pp. 368, ref. p. 313.

Fechner, G. T. Elemente der Psycophysik. Leipzig: Breitkopf and Hartel, 1889.

Feré, C. S. Sensation et mouvement. Paris, 1900; also *Anné psychologique*, 1900, VII, 69, 82, 143.

Hartshorne, H. S. Studies in deceit. N. Y.: Macmillan, 1928.

Langfeld, H. S. The aesthetic attitude. New York. Harcourt Brace, 1920, pp. 287.

Lehmann, A. G. L. Die körperliche Äusserungen Psychischer Zustande, 1901, II, 291, 1905, III, 403.

Moss, F. A. A study of animal drives. *J. Exper. Psychol.*, 1924, 7, 165–185.

Nafe, J. P. An experimental study of the affective qualities. *Amer. J. Psychol.*, 1924, 35, 507–544.

Royce, J. Outlines of Psychology. N. Y.: Macmillan, 1903, pp. 178–188.

Ruckmick, C. A. The psychology of pleasantness. *Psychol. Rev.*, 1925, 32, 362–383.

Shepard, J. F. Organic changes and feeling. *Amer. J. Psychol.*, 1906, 17, 522.

Simmons, R. The relative effectiveness of certain incentives in animal learning. *Comp. Psychol. Monog.*, 1924, No. 7.

Skaggs, E. B. Studies in attention and emotion. *J. Comp. Psychol.*, 1930, 10, 375–419.

Smith, W. Whately. Experiments on memory and affective tone. *Brit. J. Psychol.*, 1921, 11, 236–250.

Stevens, H. C. A plethysmographic study of attention. *Amer. J. Psychol.*, 1905, 16, 409–483.

Warden, C. J. Animal motivation; experimental studies on the albino rat. N. Y.: Columbia Univ. Press, 1931. Also article by Jenkins, T. N., Warden, L. H., and Warden, C. J. Standard apparatus for the study of animal motivation. *J. Comp. Psychol.*, 1926, 6, pp. 361–382.

Washburn, M. F., and Pisek, F. Galvanometer experiments with revived emotions as a test of emotional and phlegmatic temperaments. *Amer. J. Psychol.*, 1925, 36, 459–461.

Wheeler, R. H. An experimental investigation of the process of choosing, Eugene, Oregon; Univ. of Oregon Press, 1920, pp. 59. Also The action consciousness. *Brit. J. Psychol.*, 1929, 19, 253.

Wundt, W. Physiological Psychology. N. Y.: Macmillan (6th ed.), 1910, II, p. 310.

APPENDIX A

ESSENTIAL STATISTICAL METHODS FOR EXPERIMENTAL PSYCHOLOGY

ANY complete or adequate exposition of statistical methods is beyond the scope of this book but there are certain methods which are indispensable to work in general experimental psychology. These are briefly set forth below.

1. *Measures of Central Tendency.* The great variability of the results of psychological observations makes single measurements highly unreliable. It is necessary to multiply the measures until some degree of statistical reliability is reached. The first necessary statistical tool is a value which shall group these measures together into a single representative value. Such a value represents the center about which the single measures are distributed and is therefore called a measure of central tendency. There are three — the mean, the median, and the mode. The Mean is obtained by adding the individual measures together and dividing by the number of cases. Its formula is therefore $Av. = \frac{\Sigma M}{N}$, where Σ = sum of, M = the individual measures, and N = the number of cases. The Median is obtained by arranging the separate measures in order of size from largest to smallest, and then selecting that measure on either side of which one half of the total number of measures fall. Where the total number of cases is even, the median is a point on the scale halfway between the two middle measures. The Mode is the measure which occurs most often and hence has the highest frequency. There may be more than one mode in a distribution.

In addition to these measures, there are the Quartiles. The first quartile of a distribution is the point below which lie one fourth of the measures. The third quartile is the point below which lie three fourths of the measures.

Use of Mean, Median, and Mode. The mean has the advantage of giving each measure in a series its due weight, but for the same reason it is not always the most representative measure, since one or more very large measures at one extreme of the distribution can disturb the position of the mean very radically. It is safer with large distributions in which isolated measures do not receive undue weight.

The median, since it is based on position in the series rather than on size of individual measures, is a more representative average for small distributions, although it lacks mathematical exactness. And, for large distributions, the mean and median approximate each other closely. The mode depends on a single measure — the one having greatest frequency — and hence is quickly obtained but is quite unstable except in very regular distributions, and is lacking in precision as a final measure.

2. *Measures of Variability.* A measure of central tendency is representative of the distribution to the extent that the individual values approach it. The values may be widely or narrowly scattered about it. To determine this, certain measures of variability are used. About the simplest but least reliable way to estimate the scatter of a distribution is to determine the difference between the highest and lowest measures in it. But these might be widely displaced relative to the mass. The commonest reliable measures are the average deviation, the standard deviation, and the probable error.

The Average Deviation. This is simply an average of the deviations of each one of the individual values in a distribution from the measure of central tendency, taken without regard to sign. The formula is $A.D. = \frac{\Sigma D}{N}$, where D is deviations and N is number of cases. Deviations are usually computed from the arithmetic mean.

The Standard Deviation. The common symbol for this measure is sigma, written σ. It is defined as the square root of the average of the deviations from the mean squared. The formula is $\sigma = \sqrt{\frac{\Sigma D^2}{N}}$. It is obtained by finding the deviations of each measure in the distribution from the mean, squaring and summing them, dividing this by the number of cases, and finding the square root of the quotient. It differs from the average deviation only in that the deviations are squared, and the square root extracted. According to Garrett the standard deviation is less affected by chance variations than the average deviation.

With a long list of measures, the computing of the separate deviations becomes excessively tedious. The following shorthand method is recommended:

Arrange measures in convenient class intervals, and place in column I. Set down the frequencies of the class intervals in column II, headed *F*.

Locate the assumed mean of the distribution in that class interval which has an approximately equal total frequency above and below it. Place in column III, headed *X*, the number of steps which each class interval is from the mean class interval, which is itself given a value of zero. Then column IV is obtained by multiplying column II by column III, under the heading *FX*. Finally, column V is computed by multiplying column III by column IV, and is headed FX^2.

The formula for the standard deviation is then $\sqrt{\frac{\Sigma FX^2}{N} - \left(\frac{\Sigma FX}{N}\right)^2}$. This may be reconverted from class intervals back to measures by multiplying the radical by the size of a single class interval. The full formula is therefore $\sqrt{\frac{\Sigma FX^2}{N} - \left(\frac{\Sigma FX}{N}\right)^2} \times h$, where h = size of class interval. Below is a sample computation:

Class Intervals	*F*	*X*	*FX*	FX^2
136–139.9	3	4	12	48
132–135.9	5	3	15	45
128–131.9	16	2	32	64
124–127.9	23	1	23	23
120–123.9	52	0	0	0
116–119.9	49	− 1	− 49	49
112–115.9	27	− 2	− 54	108
108–111.9	18	− 3	− 54	162
104–107.9	7	− 4	− 28	112
	N = 200		*ΣFX = − 103	ΣFX^2 = 611

$$\text{Standard Dev.} = \sqrt{\frac{611}{200} - \left(\frac{-103}{200}\right)^2} \times 4$$
$$= 1.67 \times 4$$
$$= 6.68$$

---

* N.B. The symbol Σ means "sum of." Hence ΣFX means the algebraic sum of the *FX* column.

The Probable Error. This measure of variability is very significant because 50 per cent of all the cases in a distribution lie within the range represented by measuring off one *P.E.* on either side of the mean. The *P.E.* is obtained from the standard deviation by multiplying by the decimal .6745.

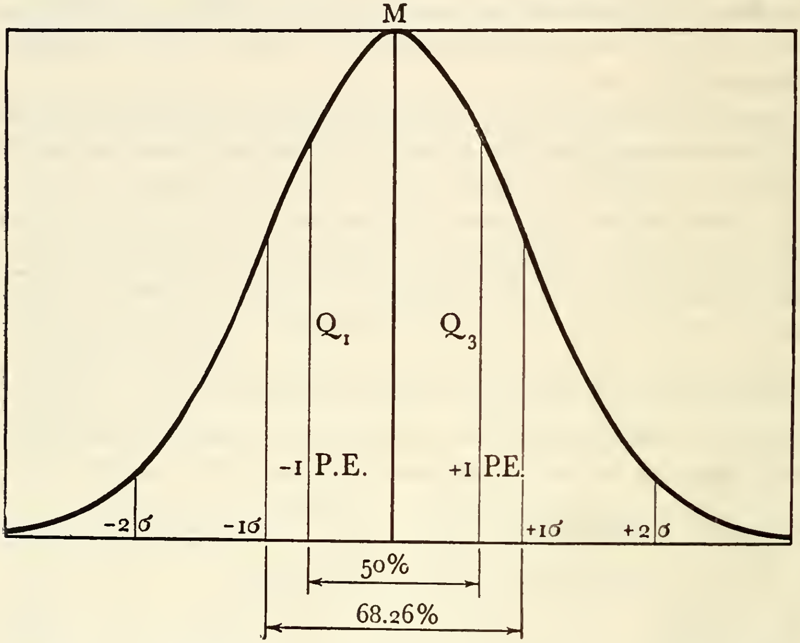


FIG. 113. Normal probability curve with standard deviation, probable error, and semi-interquartile range indicated

The Semi-interquartile Range. The symbol is *Q.* It is equal to half the distance between the first and third quartiles, and the formula is $\frac{Q_3 - Q_1}{2}$. In other words, it includes 25 per cent of the cases in either direction from the mean in a normal distribution, and shows the limits of the 50 per cent range of cases, as does the *P.E.*

In Figure 113 are indicated, on the normal probability curve of frequency, the measures σ, *P.E.*, and *Q.*

Note that the standard deviation is largest and that if three standard deviations are measured off along the base either way from the mean, practically the entire distribution is included. The average deviation is next largest and the *P.E.* is smallest. It is often convenient to translate the various measures of variability into terms of one another. This can be done in terms of the following table:

$$\begin{aligned} A.D. &= .7979\,\sigma \\ \sigma &= 1.2533\,A.D. \\ P.E. &= .6745\,\sigma \\ P.E. &= .8453\,A.D. \end{aligned}$$

3. *The Reliability of Measures of Central Tendency.* It is also necessary to know the degree to which a measure of central tendency is the true measure. Whereas measures of variability of a distribution show to what extent the individual measures deviate from the average, measures of reliability estimate the degree to which the average itself is likely to shift if an entirely new sampling of measures is obtained. It predicts the amount of variability of a series of averages of successive distributions obtained under identical conditions. If such a series of averages should scatter widely, the reliability of the given average would be low.

This prediction can be made if two things are known: (1) the variability of the individual measures from the average, and (2) the number of cases from which the average was computed. Actually reliability of an average increases not as the number of cases, but as the square root of the number of cases. Therefore the reliability of any measure of central tendency can be expressed as a ratio between the variability of the distribution and the square root of the number of cases.

Three such measures are used: the standard error of the mean, the probable error of the mean, and the probable error of the median.

The Standard Error of the Mean. The formula for it is $\sigma\ av. = \frac{\sigma\ dis.}{\sqrt{N}}$, where σ *av.* means the standard error of the average; σ *dis.* means the standard deviation of the distribution; and N is the number of cases. For example, if the average of a series of measures is 100 and the standard deviation is 10, then if there are 36 cases in the distribution, the standard error of the mean will be $\frac{10}{6} = 1.7$. But if there are 100 cases, then the standard error will be only $\frac{10}{10} = 1.0$. This means that, in the latter case, two thirds of all averages from further samplings of the same size should fall within the limits $100 + 1$ and $100 - 1$, or 99 and 101.

The Probable Error of the Mean. The formula for this is $P.E.\ av. = \frac{P.E.\ dis.}{\sqrt{N}}$. It can also be stated as a function of the standard error, namely: $P.E.\ av. = .6745\ \sigma\ av.$ Since the *P.E.* of the distribution includes 50 per cent of all the cases, therefore one half of all averages obtained from further samplings of the same size will fall within a range above or below the mean by the amount of the *P.E.*

The Probable Error of the Median. The formula for this is $P.E.\ med. = \frac{5\ P.E.\ dis.}{4\sqrt{N}}$.

4. *The Reliability of the Difference between the Averages of Two Different Distributions.* It is often necessary to determine whether a discovered difference between the averages of two different series of measures is really significant, or only a chance difference. For example, suppose the problem is to determine whether visual reaction times are significantly longer than auditory reaction times. Suppose that a hundred measures of a subject's visual reaction time yield an average time of 200 sigma (thousandths of a second), with a standard error of 9; whereas a hundred measures of his auditory reaction time yield an average time of 140 sigma, with a standard error of 6. The question is, is the difference between 200 and 140 significant? This of course depends on the degree of stability of the two means, i.e. whether they are reliable measures of the central tendency of their respective distributions.

The simplest way of answering the question is to note how much the individual measures in the two distributions tend to overlap. Are there many of the visual reaction times which are shorter than the average auditory reaction time; and are there many of the auditory reaction times which are longer than the average visual reaction time? If frequency distributions of the two series are made on the same base line the amount of overlapping can be determined by inspection of the curves. The result can be expressed in terms of the per cent of measures in each distribution which overlap the mean of the other distribution. Figure 114 illustrates the manner in which the amount of overlapping can be judged from simple inspection of the frequency polygons.

But this is only a rough method. A more quantitatively accurate method is the following:

Referring back to the illustration of the visual and auditory reaction times, it was assumed that the average visual reaction time was 200 sigma ± 9; while the average auditory time was 140 sigma ± 6. Now it is possible to predict the degree to which the difference (60 sigma) between the two averages would vary if further measures were taken, by finding out either the standard error of the difference, or the probable error of the difference. The former measure has the following formula: $\sigma_D = \sqrt{(\sigma av._1)^2 + (\sigma av._2)^2}$ where σ_D means standard error of the difference and $\sigma av._1$ and $\sigma av._2$ means standard error of the first average and second average, respectively.

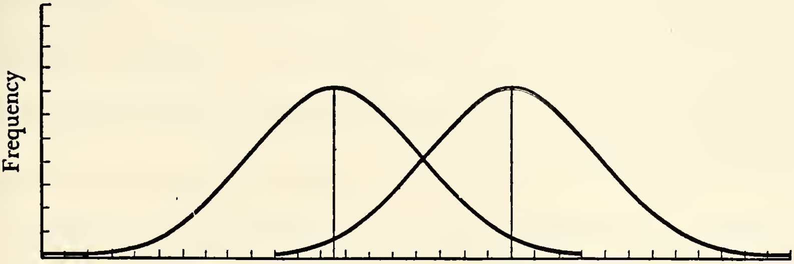


FIG. 114. Overlapping of distributions

The formula for the probable error of the difference is as follows:

$$P.E._D = \sqrt{(P.E._{av._1})^2 + (P.E._{av._2})^2}$$

For example, in the illustration given, the discovered difference between the two averages has a standard error of $\sqrt{(9)^2 + (6)^2}$, or 10.8. The question is, is a difference of 60 which has a standard error of 10.8 significant? To answer this it is necessary to find the ratio between the difference and its standard error, thus: $\frac{D}{\sigma_D}$.

From the size of the resulting quotient it is possible to determine the number of chances in 100 that the direction of the difference discovered between the two averages will be confirmed by further sampling. For example, if the quotient is 1.0, the chances are 84 in 100. If it is 1.5, the chances are 93 in 100. If it is 2.0, the chances are 98 in 100. If it is 2.5, the chances are 99 in 100. And if it is 2.7 or more (i.e. approximately 3.0), the chances are approximately 100 out of 100.

For experimental purposes it is agreed that, to be significant, a difference must exceed its standard error by a large enough ratio so that the chances are approximately 100 out of 100 that the direction of the difference will be confirmed. Therefore it can be seen that the quotient must be equal to or greater than 2.7 if the difference is to be considered significant.

Again referring back to the illustration given, and applying the formula $\frac{D}{\sigma_D}$, we obtain the ratio $\frac{60}{10.8}$, or 5.5. We may therefore conclude that there is a significant difference between these visual and auditory reaction times.

The same procedure can be used with the $P.E._D$, except that in this case the quotient resulting from the ratio $\frac{D}{P.E._D}$ must be equal to or greater than 4. The accompanying chart shows the chances in 100 computed for all values of the quotient $\frac{D}{P.E._D}$ between 1.0 and 4.0.

Quotient	*Chances in 100*
1.0	75
2.0	91
3.0	98
4.0	Approx. 100

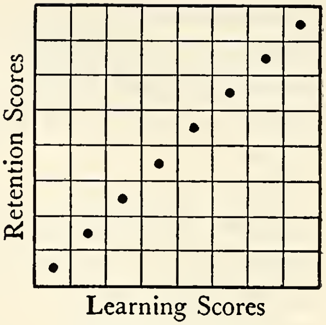
It should be noticed that the formulae for σ_D and $P.E._D$, as given, assume that the two distributions from which they were computed are uncorrelated. But if a correlation exists between the measures in the two distributions, then the following formulae should be substituted:

$$\sigma_D = \sqrt{(\sigma_{av._1})^2 + (\sigma_{av._2})^2 - 2r\,\sigma_{av._1}\,\sigma_{av._2}}$$

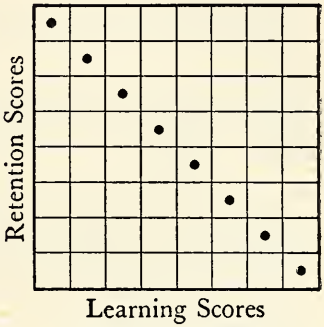
$$P.E._D = \sqrt{(P.E._{av._1})^2 + (P.E._{av._2})^2 - 2r\,P.E._{av._1}\,P.E._{av._2}}$$

The symbol r stands for the coefficient of correlation between the two distributions.

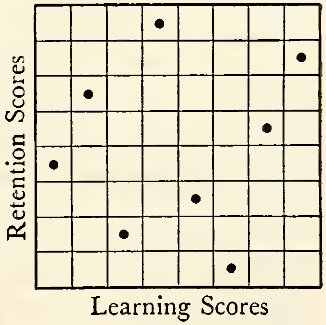
5. *Correlation.* It is frequently necessary in psychological experiments to know the degree to which the individual measures in any two series of measurements vary concomitantly. In fact one of the criteria by which we judge the causal relation between two variables is the degree to which variations in one are accompanied by corresponding variations in the other. For example, suppose the question at issue is whether there is a real relationship between



PERFECT POS. CORRELATION



PERFECT NEG. CORRELATION



ZERO CORRELATION

Fig. 115. Perfect positive, negative and zero correlations

ability to memorize and ability to retain. Are these two abilities related in any significant way? If they are, then, provided we take a group of subjects, the individual members of which differ widely in memorial ability, they should show corresponding differences in retentive ability. That is, those individuals who rank high in memorial ability should rank high in retentive ability, and those who rank low in the former should rank low in the latter. But mere inspection of the individual scores in the two distributions would not enable us to determine how great a degree of correlation or concomitant variation existed. More refined methods are needed.

(a) *Graphical Representation.* One method is to locate each individual's position on a graph, in which the ordinate values represent scores in one ability — say memory — and the abscissa values represent scores in the other ability — retentiveness.

When the entire group of individuals have been located on such a graph, they should occupy positions which show a characteristic distribution depending on the degree of correlation between the two abilities. For example, if the two abilities are perfectly related, then it can be seen, from the accompanying graph, that the points must fall along a diagonal line running from the lower left to the upper right corner. This is called a perfect positive correlation. And if any high degree of correspondence exists, the distribution should approach this form. But, on the contrary, if there is a perfect inverse correlation between the two abilities, then the points should distribute along a diagonal line running from the upper left to the lower right corner. This is called a perfect negative correlation. This would mean that every individual shows an inverse rank in the two abilities; i.e. the lowest in memorial ability are highest in retentiveness and vice versa.

If, however, there is no relation between the two sorts of ability, then the individual points should be evenly scattered over the entire area with no direction indicated. This is called a zero correlation. When such a graph has been plotted, one can tell by inspection how nearly the distribution of points resembles the first, second, or third form, and hence whether a positive, negative, or zero correlation is present.

In order to express this relation in terms of a single formula or measure, however, it is necessary to employ either the Pearson product moment correlation coefficient, the symbol for which is "r," or the rank order correlation coefficient whose symbol is ρ. The former coefficient is used when it is desired to take into consideration the differences in absolute magnitude of the individual measures compared, whereas the latter coefficient is used where only the differences in rank between paired measures are taken account of.

(b) *The Rank Order Correlation Coefficient.* This method is most frequently used for the hasty calculation of correlations because of its relative simplicity. The formula is $\rho = 1 - \frac{6\Sigma D^2}{N(N^2 - 1)}$, in which Σ means "the sum of"; D^2 means "the differences squared," and N stands for the number of pairs on which the correlation is being computed. The steps in computation may be illustrated as follows:

Suppose measures have been obtained, on ten subjects, of (a) number of presentations necessary to learn a list of syllables, and (b) number of syllables recalled after a day.

Subject	*Trials to Learn*	*Syllables Recalled*	*Ranks in Column* 1	*Ranks in Column* 2	*D*	*D*²
A	15	4	10	10	0	
B	4	15	2	2	0	
C	8	5	5	9	4	16
D	7	14	4	3	1	1
E	14	6	9	8	1	1
F	9	11	6	5	1	1

Subject	Trials to Learn	Syllables Recalled	Ranks in Column 1	Ranks in Column 2	D	D^2
G	2	17	1	1	0	
H	5	12	3	4	1	1
I	12	10	8	6	2	4
J	11	8	7	7	0	

$N = 10$ subjects

$\Sigma D^2 = 24$

$6\Sigma D^2 = 144$

Supplying this value in the formula, we have

$$\rho = 1 - \frac{144}{N(N^2 - 1)} = 1 - \frac{144}{990} = 1 - .15 = +.85.$$

The steps are as follows:

1. List in column 1, the individuals on whom the two sets of measures have been obtained.

2. List in column 2, opposite each individual, his score on one of the abilities, say learning, and in column 3, his score on the other ability — recalling.

3. List in column 4, the relative rank of each individual, as shown by his score in column 2, giving the highest individual a rank of 1 and so forth. (Note that it is the best score that receives rank 1, not necessarily the highest score.)

4. List in column 5, the rank of each individual as shown by his score in column 3.

5. Compute the numerical difference between each individual's rank in columns 4 and 5, and list in column 6.

6. Square these differences and list them in column 7.

7. Add the squared differences of column 7, multiply the sum by 6, and substitute this figure in the formula.

Note that in this case a high number on "trials to learn" signifies a poor score and hence a low rank, whereas a high number on "syllables recalled" indicates a good score and hence a high rank.

It will be noticed that, in this example, the value for $6\Sigma D^2$ was smaller than the value for $N(N^2 - 1)$ and hence the value subtracted from 1.00 in the equation was less than 1.00, thereby giving a positive value to the correlation coefficient. But if the value for $6\Sigma D^2$ were larger than that for $N(N^2 - 1)$, the quotient would be greater than unity and the sign of the correlation coefficient would therefore be negative.

It should be noticed that often two or more individuals have identical scores, and hence require identical ranks. Yet the rank of the lowest individual in the group (i.e. the last one ranked) must be equal to the number of cases in the distribution, unless there is a tie for last place. Therefore each person in a series of two or more tied scores is given a rank equal to the midpoint of the range of ranks which they cover. For example, if the second and third highest ranks go to persons having identical scores, they will each be given a rank of $2\frac{1}{2}$, rather than ranks of 2 and 3, respectively. And the next lower person will receive a rank of 4. And if the second, third, and fourth highest ranks all go to persons having identical scores, they will each be given a rank of 3, rather than 2, 3, and 4, respectively; and the next lower person will receive a rank of 5.

(c) *The Reliability of the Rank Order Correlation Coefficient.* This depends on the size of the coefficient in relation to the number of cases from which it was computed. The formula for the *P.E.* of the correlation coefficient is $P.E.\ \rho = \frac{.706(1 - \rho^2)}{\sqrt{N}}$. In the example given, substituting the values of ρ and of N, we have

$$P.E.\ \rho = \frac{.706 \times (1 - .72)}{\sqrt{10}} = \pm .06.$$

The coefficient of correlation may therefore be written: $\rho = + .85 \pm .06$. This means that the chances are even that, in future samplings, the correlation coefficients obtained would fall within the limits of .80 to .92.

The reliability of the correlation coefficient may be determined from its *P.E.* by the formula $\frac{\rho}{P.E.\ \rho}$. If this quotient is 4 or more, it is assumed for general purposes that the correlation coefficient is reasonably reliable.

(d) *The Product Moment Correlation Coefficient, or Pearson "r."* If a rank order coefficient of correlation has been obtained, it is possible to convert it into a Pearson "*r*" by referring to a table of equivalent values such as Table XX in Garrett's *Statistics in Psychology and Education*, p. 192.

The usual form of the Product Moment formula, where actual averages of the two distributions are known, is $r = \frac{\Sigma xy}{N\sigma_x\sigma_y}$. If we substitute $\sqrt{\frac{\Sigma x^2}{N}}$ for σ_x and $\sqrt{\frac{\Sigma y^2}{N}}$ for σ_y, then by cancelling the

N's, the formula becomes $r = \dfrac{\Sigma xy}{\sqrt{\Sigma x^2} \times \sqrt{\Sigma y^2}}$, where x and y are the deviations of the respective scores in the first and second distributions. With a small number of cases — under 40 — this coefficient can be worked out without preparing a correlation table.

Using the same illustration as before, the steps in computation of this coefficient are shown below:

Step I. List the individuals in a column and list their scores in the two abilities in parallel columns.

Step II. Find deviations of each score in the first distribution from the average, and place in column headed x. Find deviations of scores in the second distribution from the average and place in column headed y.

Step III. Square all the x deviations and the y deviations and enter in columns headed x^2 and y^2, respectively.

Step IV. Multiply the x by the y deviations and place products in column headed xy.

Step V. Add the x^2 column, the y^2 column, and the xy column, and substitute the obtained values in the formula.

Subject	*Trials to Learn*	*Syllables Recalled*	x	y	x^2	y^2	xy
A	15	4	6.3	− 6.2	39.69	38.44	− 39.06
B	4	15	− 4.7	4.8	22.09	23.04	− 22.56
C	8	5	− 0.7	− 5.2	0.49	27.04	3.64
D	7	14	− 1.7	3.8	2.89	14.44	6.46
E	14	6	5.3	− 4.2	28.09	17.64	− 22.26
F	9	11	0.3	0.8	0.09	0.64	0.24
G	2	17	− 6.7	6.8	44.89	46.24	− 45.56
H	5	12	− 3.7	1.8	13.69	3.24	− 6.66
I	12	10	3.3	− 0.2	10.89	0.04	− 0.66
J	11	8	2.3	− 2.2	5.29	4.84	− 5.06
	10|87	10|102			168.10	175.60	− 144.40
	8.7	10.2			Σx^2	Σy^2	Σxy

$$r = \frac{-144.40}{\sqrt{168.10} \times \sqrt{175.60}}$$

$$r = \frac{-144.4}{12.96 \times 13.25} = -.85$$

This of course should be interpreted as a positive correlation of .85 because high scores in trials to learn mean low scores in learning ability, while high scores in syllables recalled mean high retentive ability.

The probable error of this coefficient is obtained from the formula

$$P.E._r = \frac{.6745(1 - r^2)}{\sqrt{N}}$$

Supplying the appropriate values, we have

$$P.E._r = \frac{.6745(1 - .72)}{3.2} = \pm .06$$

APPENDIX B

THE PSYCHOPHYSICAL METHODS

THE problem of determination of absolute and difference thresholds in sensation, as well as determinations of apparent equality of two stimuli or two stimulus differences, has led to the development of the psychophysical methods. Three main types of method exist: "the method of mean error", "the limiting method", and "the constant method".

The *method of mean error* is also known as the reproduction method, because, in it, the subject manipulates one of the paired stimuli. It is used for determining equality of stimuli. For example, in comparing the respective lengths of two lines, one line, the standard, is set at a given length, and the variable line is then moved about by the subject until it is judged to be just equal to the standard. When a series of such judgments has been made and recorded, the difference between the average of these determinations and the length of the standard gives the constant error. But if the deviations of each separate judgment from the standard are computed without regard to sign and then their average computed, the result is the "crude average error".

There are certain constant sources of error in such judgments. These result from (1) whether the variable line is shorter or longer than the standard line, (2) whether the two stimuli are presented simultaneously or successively, and (3) how they are arranged spatially relative to one another, because of the space-time errors. In order to eliminate these factors, it is necessary to vary the relative positions of the two stimuli in all possible ways so that the errors tend to cancel out.

In the *limiting method*, the variable is not manipulated by the subject, but its values are fixed by the experimenter. This method is also known as the "method of minimal changes", and the "method of just noticeable differences", because its purpose is to present, successively, with a constant stimulus, a variable stimulus whose objective difference from the constant either increases or decreases by minimal steps until a value is found at which the subject is just able to judge that the value of the variable is less or more than that of the constant. One series of graded values of the variable constitutes a series of observations. If the series begins with values appreciably greater than the standard and descends toward it, then the value which is found to be just noticeably greater constitutes the upper difference threshold. But when the series begins with values appreciably lower than the standard and ascends toward it, the value which is found to be just noticeably smaller constitutes the lower difference threshold. For the determination of the absolute thresholds of sensation, there is no standard against which to compare the variable; hence the procedure becomes one of presenting a graded series of values of the stimulus, beginning with one well above or well below the threshold and then progressing up or down until the stimulus becomes just noticeable.

Both upper difference threshold and lower difference threshold may be determined in the same series by progressively going from a value appreciably greater than the standard to one appreciably less and then reversing the process. Slightly different results are obtained, depending on the direction of the series. These and other errors due to the expectation of the subject must be compensated for by varying the procedure from time to time and by tricking the subject into greater attentiveness by introducing occasional pairs in which standard and variable are equal.

The *constant method* is also called the "method of right and wrong cases" because each value of the variable is presented several times with the standard, in any series of observations. This makes possible the determination of the percentage of times the variable was judged appreciably different from the standard. The limen is then selected as that value of the variable which is judged appreciably different (greater or less) from the standard in 50 per cent of the cases. That is, it is assumed that the ratio of right to wrong cases is 50 per cent at the limen. If none of the intervals presented by the experimenter yields just 50 per cent right and 50 per cent wrong answers, then the limen can be computed from the nearest values in the following way: Assume that the problem is to determine the differential limen for pitch. Suppose that when the variable tone is two vibrations per second lower than the standard, the subject gives 30 judgments out of 100, of lower; while when the variable is three vibrations per second lower than the standard, his percentage of right answers is 70. Then the limen lies between two and three vibrations; in this case at two and one-half vibrations. If there are several values above and below the unknown 50 per cent point, then a smoothed curve can be drawn through these points

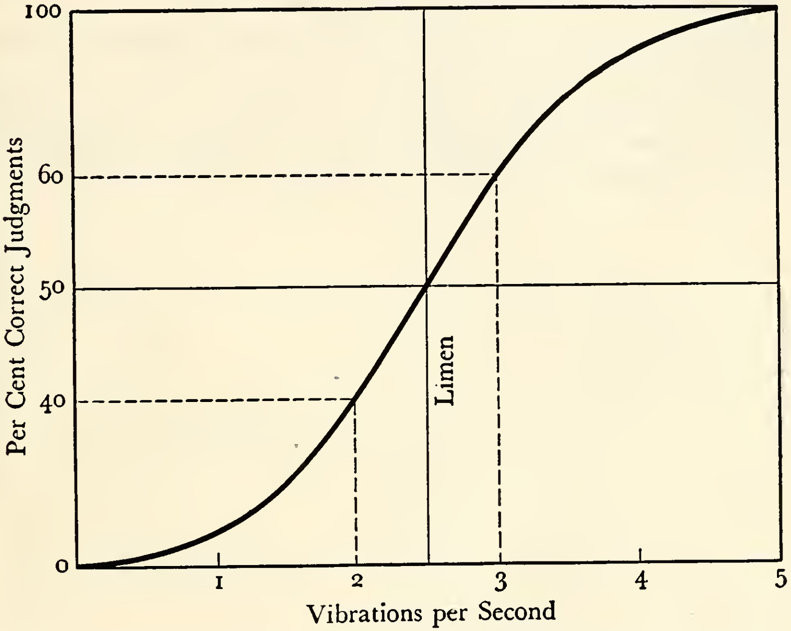


FIG. 116. Graphical method of determining threshold value

on a frequency graph whose ordinate is the frequency of right answers at each value of the variable, and the abscissa represents the different values of the variable. A line drawn from the 50 per cent level on the ordinate, parallel to the abscissa, will cut the curve at a point directly above the true threshold value on the abscissa. (See Figure 116.)

A complicating factor is the occurrence of reversals, where increasing objective distances between standard and variable produce either no change in the number of right cases or an actual decrease. These would show as irregular drops in the above frequency curve. Reversals tend to disappear with sufficient sampling.

Another complicating factor is that the subject frequently gives answers of "doubtful" or "equal to the standard" when the distance between the values is slight. Of the various ways of disposing of such answers, i.e. ignoring them, forbidding their use, or splitting them equally each way, the last way seems most satisfactory.

The *method of equal appearing intervals* differs from the methods already described only in that it is used where the problem is to determine under what conditions the differences between two different pairs of stimuli will be judged equal.

The results from the use of the different psychophysical methods do not agree perfectly because of the difference in the disturbing factors involved in each. But they constitute the most reliable methods known for determining sensory thresholds and subjective estimates of likeness and difference between objective stimuli.

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